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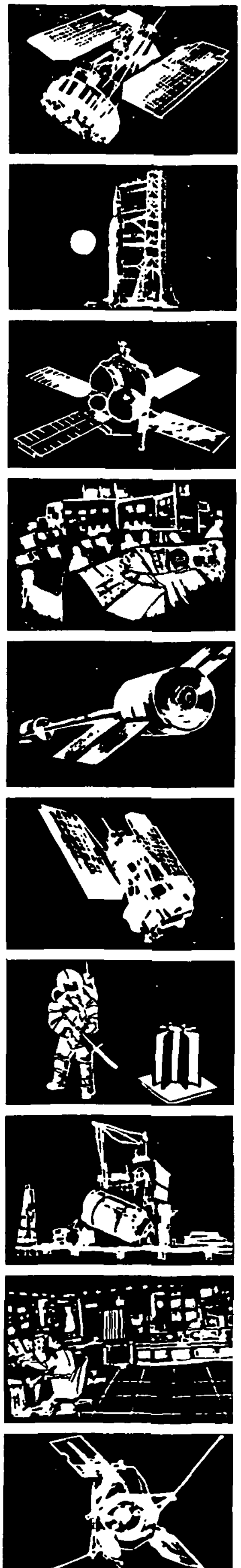

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FINAL REPORT

REDUCTION OF TRUNCATION ERRORS IN MODAL ANALYSIS

ADDENDUM
DAMUS USERS MANUAL

PREPARED FOR:

NATIONAL AERONAUTICS
AND
SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
UNDER:
CONTRACT NAS 8-28167

GENERAL ELECTRIC

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Prepared for

George C. Marshall Space Flight Center

Prepared Under: Contract NAS 8-28167

NASA-MSFC Technical Monitor: Dr. J.R. Admire

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GENERAL ELECTRIC

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FOREWORD

The program reported herein was performed by the General Electric-Space Division, Valley Forge, Pa., for the George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama, under Contract NAS 8-28167. The performance period for the work was 2 December 1971 to 29 June 1973. The principal investigator was Edward J. Kuhar and the program manager was Clyde V. Stahle. The NASA Technical Monitor was Dr. John R. Admire who provided valuable guidance throughout the course of the program.

The results of the study are described in the main volume of this report and include the theoretical development of the dynamic transformation method, numerical results from the application of the method to several sample problems, and some comparisons with other available methods of analysis.

The separate addendum to this report provides the user instructions for the DAMUS computer program (Dynamic-transformation Adapted to Modal-synthesis Using Stiffness Coupling) which implements the method developed under this program.

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Nomenclature

$[m]$	=	mass matrix for substructure in $\{x\}$ physical coordinates
$[k]$	=	stiffness matrix for substructure in $\{x\}$ physical coordinates
$[\phi]$	=	matrix of substructure eigenvectors in $\{x\}$ coordinates
$[M_T]$	=	mass matrix for total structure in $\{x\}$ physical coordinates
$[K_T]$	=	stiffness matrix for total structure in $\{x\}$ physical coordinates
$[\Phi_x]$	=	matrix of eigenvectors for total structure in $\{x\}$ physical coordinates
$[M]$	=	generalized mass matrix for total structure in $\{q\}$ modal coordinates
$[K]$	=	generalized stiffness matrix for total structure in $\{q\}$ modal coordinates
$[\gamma]$	=	matrix of eigenvectors for total structure in $\{q\}$ modal coordinates
$[T]$	=	dynamic transformation matrix
$[R]$	=	transformation matrix defining the relationship of the reduced coordinates, $\{q^R\}$, to the kept coordinates $\{q^K\}$.
$\{x\}$	=	physical coordinates
$\{q\}$	=	generalized modal coordinates
Ω	=	system circular frequency
ω	=	substructure circular frequency
p	=	reduction circular frequency
n	=	number of degrees of freedom in structure

Subscripts

i	=	refers to the i^{th} subset, term, or substructure
Δ	=	incremental mass from coupling spring
CPL	=	incremental stiffness from coupling spring
k	=	kept coordinates
r	=	reduced coordinates

Superscripts

k	=	kept coordinates
r	=	reduced coordinates
A	=	attachment coordinates
I	=	interior coordinates not attached to any other substructure
$-$	=	revised value
$\cdot\cdot$	=	second time derivative
ij	=	particular submatrix partition

SECTION 1

INTRODUCTION

This document describes a Fortran IV computer program used to perform modal synthesis by stiffness coupling using the dynamic transformation method. The program has been named DAMUS (Dynamic-transformation Adapted to Modal-synthesis Using Stiffness-coupling). The program begins with the entry of a substructure's mass and stiffness matrix. The eigenproblem for the individual substructure is solved. Provisions are included for a maximum of 20 substructures (100 DOF max/substructure) which may be coupled by 100 stiffness matrix springs (100 DOF/spring). The substructures are then coupled together via coupling springs, and the dynamic transformation is used to reduce the size of the eigenproblem. After solving for the coupled system eigenvalues and vectors, the user may elect to backsubstitute selected modes. The total number of modes treated by the program is 300 consisting of 100 kept coordinates (maximum eigenvalue size) and 200 coordinates reduced by the dynamic transformation. For user flexibility, six major entry points have been included in DAMUS.

Input data for DAMUS is mainly accomplished by the READ and READIM FORMA subroutines. Output data to be saved is written on files generated by the WTAPDS and WTAPSS subroutines written specifically for DAMUS. Those files which contain data to be saved should be copied to tape after the execution of DAMUS. A total of 12 files have been defined for use by the program. Depending on user options, the number of files used at any one time will vary; and at no time will all twelve be used simultaneously.

SECTION 2

THEORETICAL DISCUSSION

2.1 BASIC THEORY FOR STIFFNESS COUPLING

The stiffness coupling method of modal synthesis assembles the complete structure in the same manner as the displacement method for structural analysis. The total structure may be represented by a number of substructures connected through flexible links. Each substructure is analyzed without the flexible links to determine the component vibration modes with free attachment coordinates. The flexible links are represented by a stiffness matrix relating the interface forces from one set of substructure attachment coordinates to another.

The method of substructuring for stiffness coupling may best be illustrated by considering a total structure consisting of only two substructures. The general undamped equation of motion for the ith substructure in terms of its generalized mass matrix, $[m_i]$, and generalized stiffness matrix, $[k_i]$, is given by

$$[m_i]\{\ddot{x}_i\} + [k_i]\{x_i\} = 0 \tag{1}$$

where the coordinates $\{x_i\}$ describe physical motions of the mass points. Each substructure has two sets of coordinates which will be referred to as attachment coordinates, $\{x_i^A\}$, and internal coordinates, $\{x_i^I\}$. The attachment coordinates are those degrees of freedom (DOF) which are connected to another substructure via a stiffness matrix or coupling spring. The internal

coordinates are those DOF which are not connected to any other substructure. It is important to note that for stiffness coupling the coordinates belonging to one particular substructure are not common to any other. If n_i represents the size of the ith substructure and n the size of the total structure comprised of λ substructures, then n will be given by

$$n = \sum_{i=1}^{\lambda} n_i \qquad (2)$$

Having defined two sets of coordinates for each substructure, Eq. (1) may be written in partitioned form as

$$\underset{n_i \times n_i}{\left[\begin{array}{c|c} m_i^{11} & m_i^{12} \\ \hline m_i^{21} & m_i^{22} \end{array}\right]} \underset{n_i \times 1}{\left\{\begin{array}{c} \ddot{x}_i^A \\ \hline \ddot{x}_i^I \end{array}\right\}} + \underset{n_i \times n_i}{\left[\begin{array}{c|c} k_i^{11} & k_i^{12} \\ \hline k_i^{21} & k_i^{22} \end{array}\right]} \underset{n_i \times 1}{\left\{\begin{array}{c} x_i^A \\ \hline x_i^I \end{array}\right\}} = 0 \qquad (3)$$

Now consider the total structure to be described by a mass matrix, $[M_T]$, and a stiffness matrix, $[K_T]$, such that

$$\underset{n \times n}{[M_T]} \underset{n \times 1}{\{\ddot{x}_T\}} + \underset{n \times n}{[K_T]} \underset{n \times 1}{\{x_T\}} = 0 \qquad (4)$$

where

$$\underset{n \times n}{[M_T]} = \begin{array}{c} \left[\begin{array}{c|c} M_T^{11} & 0 \\ \hline 0 & M_T^{22} \end{array}\right] \end{array} \begin{array}{c} n_1 \\ n_2 \end{array}$$

$$\underset{n \times n}{[K_T]} = \left[\begin{array}{c|c} K_T^{11} & K_T^{12} \\ \hline K_T^{21} & K_T^{22} \end{array}\right] \begin{array}{c} n_1 \\ n_2 \end{array} \qquad (5)$$

$$\underset{n \times 1}{\{x_T\}} = \left\{\begin{array}{c} x_1 \\ \hline x_2 \end{array}\right\} \begin{array}{c} n_1 \\ n_2 \end{array}$$

If we describe the connecting structure between $\{x_1^A\}$ and $\{x_2^A\}$ by a mass matrix, $[m_\Delta]$, where

$$\underset{(n_1^A+n_2^A)\times(n_1^A+n_2^A)}{[m_\Delta]} = \begin{array}{c} \left[\begin{array}{c|c} m_{\Delta_1}^{11} & 0 \\ \hline 0 & m_{\Delta_2}^{22} \end{array}\right] \begin{array}{c} n_1^A \\ n_2^A \end{array} \\ \begin{array}{cc} n_1^A & n_2^A \end{array} \end{array} \tag{6}$$

and a stiffness matrix, $[k_{CPL}]$, relating the nodal forces, $\{F_i^A\}$, to $\{x_i^A\}$ by the equation

$$\underset{(n_1^A+n_2^A)\times 1}{\left\{\begin{array}{c} F_1^A \\ \hline F_2^A \end{array}\right\}} = \begin{array}{c} \left[\begin{array}{c|c} k_{CPL}^{11} & k_{CPL}^{12} \\ \hline k_{CPL}^{21} & k_{CPL}^{22} \end{array}\right] \\ \begin{array}{cc} n_1^A & n_2^A \end{array} \end{array} \left\{\begin{array}{c} x_1^A \\ \hline x_2^A \end{array}\right\} \begin{array}{c} n_1^A \\ n_2^A \end{array} \tag{7}$$

Then $[M_T]$ and $[K_T]$ may be written in partitioned form using the submatrices defined by Eqs. (3), (6) and (7):

$$\underset{n\times n}{[M_T]} = \begin{array}{c} \left[\begin{array}{c|c|c|c} m_1^{11}+m_{\Delta_1}^{11} & m_1^{12} & 0 & 0 \\ \hline m_1^{21} & m_1^{22} & 0 & 0 \\ \hline 0 & 0 & m_2^{11}+m_{\Delta_2}^{11} & m_2^{12} \\ \hline 0 & 0 & m_2^{21} & m_2^{22} \end{array}\right] \begin{array}{c} n_1^A \\ n_1^I \\ n_2^A \\ n_2^I \end{array} \\ \underbrace{n_1^A \quad n_1^I}_{n_1} \quad \underbrace{n_2^A \quad n_2^I}_{n_2} \end{array} \tag{8a}$$

$$
\underset{n\times n}{[K_T]} = \begin{array}{c}
\left[\begin{array}{c|c|c|c}
k_1^{11}+k_{CPL}^{11} & k_1^{12} & k_{CPL}^{12} & 0 \\ \hline
k_1^{21} & k_1^{22} & 0 & 0 \\ \hline
k_{CPL}^{21} & 0 & k_2^{11}+k_{CPL}^{11} & k_2^{12} \\ \hline
0 & 0 & k_2^{21} & k_2^{22}
\end{array}\right]
\begin{array}{l} n_1^A \\ n_1^I \\ n_2^A \\ n_2^I \end{array} \\
\underbrace{n_1^A \quad n_1^I}_{n_1} \qquad \underbrace{n_2^A \quad n_2^I}_{n_2}
\end{array}
\tag{8b}
$$

By defining

$$
\underset{n\times n}{[M_\Delta]} = \begin{array}{c}
\left[\begin{array}{cccc}
m_{\Delta 1}^{11} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & m_{\Delta 2}^{11} & 0 \\
0 & 0 & 0 & 0
\end{array}\right]
\begin{array}{l} n_1^A \\ n_1^I \\ n_2^A \\ n_2^I \end{array} \\
\underbrace{n_1^A \quad n_1^I}_{n_1} \qquad \underbrace{n_2^A \quad n_2^I}_{n_2}
\end{array}
\tag{9a}
$$

$$
\underset{n\times n}{[K_{CPL}]} = \begin{array}{c}
\left[\begin{array}{cccc}
k_{CPL}^{11} & 0 & k_{CPL}^{12} & 0 \\
0 & 0 & 0 & 0 \\
k_{CPL}^{21} & 0 & k_{CPL}^{22} & 0 \\
0 & 0 & 0 & 0
\end{array}\right]
\begin{array}{l} n_1^A \\ n_1^I \\ n_2^A \\ n_2^I \end{array} \\
\underbrace{n_1^A \quad n_1^I}_{n_1} \qquad \underbrace{n_2^A \quad n_2^I}_{n_2}
\end{array}
\tag{9b}
$$

and recognizing the partitions belonging to each of the substructures, Eq. (4) may be written as

$$\left\{\underset{n\times n}{\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix}} + \underset{n\times n}{\begin{bmatrix} M_\Delta \end{bmatrix}}\right\}\underset{n\times 1}{\begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix}} + \left\{\underset{n\times n}{\begin{bmatrix} k_1 & 0 \\ 0 & k_2 \end{bmatrix}} + \underset{n\times n}{\begin{bmatrix} K_{CPL} \end{bmatrix}}\right\}\underset{n\times 1}{\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}} = 0 \tag{10}$$

For each substructure defined by Eq. (1), a set of eigenvalues, $\left\lceil \omega_i^2 \right\rfloor$, and a set of mass normalized eigenvectors, $[\phi_i]$, can be obtained such that

$$\underset{n_i\times n_i}{[\phi_i]^T}\ \underset{n_i\times n_i}{[m_i]}\ [\phi_i] = \underset{n_i\times n_i}{[I]} \tag{11a}$$

$$\underset{n_i\times n_i}{[\phi_i]^T}\ \underset{n_i\times n_i}{[k_i]}\ [\phi_i] = \underset{n_i\times n_i}{\left\lceil \omega_i^2 \right\rfloor} \tag{11b}$$

Using the results from Eq. (11), we can now express Eq. (10) in terms of a set of generalized modal coordinates, $\{q\}$. The coordinate transformation is given by

$$\underset{n\times 1}{\{x\}} = \underset{n\times n}{[\phi]}\ \underset{n\times 1}{\{q\}} \tag{12}$$

where

$$\underset{n\times 1}{\{x\}} = \underset{n\times 1}{\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}} \qquad \underset{n\times 1}{\{q\}} = \underset{n\times 1}{\begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix}} \tag{13a}$$

$$\underset{n\times n}{[\phi]} = \underset{n\times n}{\begin{bmatrix} \phi_1 & 0 \\ 0 & \phi_2 \end{bmatrix}} \tag{13b}$$

Substituting the transformation for $\{x\}$ into Eq. (10) and premultiplying by $[\phi]^T$ yields

$$\left\{\underset{n\times n}{[I]} + \underset{n\times n}{[\phi]^T[M_\Delta][\phi]}\right\}\underset{n\times 1}{\{\ddot{q}\}} + \left\{\underset{n\times n}{\begin{bmatrix} \left\lceil \omega_1^2 \right\rfloor & 0 \\ 0 & \left\lceil \omega_2^2 \right\rfloor \end{bmatrix}} + \underset{n\times n}{[\phi]^T[K_{CPL}][\phi]}\right\}\underset{n\times 1}{\{q\}} = 0 \tag{14}$$

Solution of Eq. (14) will result in a set of eigenvalues, $\left[\Omega^2\right]$, and then corresponding eigenvectors, $[\gamma]$. Because of the similarity transformation used to obtain Eq. (14) from Eq. (10), the eigenvalues of Eq. (10) will be equal to those of Eq. (14) and the corresponding eigenvectors, $[\Phi_x]$, of Eq. (10) will be given by

$$\underset{n\times n}{[\Phi_x]} = \underset{n\times n}{[\phi]}\,\underset{n\times n}{[\gamma]} \tag{15}$$

Eq. (14) represents the most general form of the equation of motion for stiffness coupling. This equation is generally solved by partitioning the $\{q\}$ coordinates into two groups, kept and truncated. The truncated coordinates correspond to the high frequency substructure modes and are completely omitted from the equation of motion. Those degrees of freedom remaining, the partitioned set of kept coordinates, determine the final reduced size of the eigenvalue problem to be solved.

The general form of Eq. (14) may be simplified further by including the correct $m_{\Delta i}^{ij}$ partitions from Eq. (6) in each corresponding $[m_i]$ at the substructure level. This is reasonable because we are assuming that there is no inertial coupling between substructures. This will result in $[M_\Delta]$ = 0 and Eq. (14) reduces to

$$\underset{n\times n}{[I]}\,\underset{n\times 1}{\{\ddot{q}\}} + \underset{n\times n}{[K]}\,\underset{n\times 1}{\{q\}} = 0 \tag{16}$$

where

$$\underset{n\times n}{[K]} = \underset{n\times n}{\left[\begin{array}{c|c} \omega_1^2 & 0 \\ \hline 0 & \omega_2^2 \end{array}\right]} + \underset{n\times n}{[\phi]^T}\,\underset{n\times n}{[K_{CPL}]}\,\underset{n\times n}{[\phi]} \tag{17}$$

After solving for the ω_i's and ϕ_i's, the only lengthy calculation left to be performed in order to obtain Eq. (16) is the matrix triple-product involving $[K_{CPL}]$. If we partition each $[\phi_i]$ row-wise in terms of its n_i^A and n_i^I coordinates such that

$$\underset{n_i \times n_i}{[\phi_i]} = \begin{array}{c} \begin{bmatrix} \phi_i^A \\ \hline \phi_i^I \end{bmatrix} \\ n \end{array} \begin{array}{c} n_i^A \\ n_i^I \\ \end{array} \tag{18}$$

Eq. (13b) can be written as

$$\underset{n \times n}{[\Phi]} = \begin{array}{c} \begin{bmatrix} \phi_1^A & 0 \\ \phi_1^I & 0 \\ 0 & \phi_2^A \\ 0 & \phi_2^I \end{bmatrix} \\ \begin{array}{cc} n_1 & n_2 \end{array} \end{array} \begin{array}{c} n_1^A \\ n_1^I \\ n_2^A \\ n_2^I \\ \end{array} \tag{19}$$

By forming the triple product $[\Phi]^T[K_{CPL}][\Phi]$ using Eqs. (9b) and (19) and refactoring the result in terms of the matrix partitions, the resultant form of the triple product may be expressed as

$$[\Phi^A]^T [k_{CPL}] [\Phi^A] \tag{20a}$$

where

$$\underset{(n_1^A+n_2^A)\times n}{[\Phi^A]} = \begin{array}{c} \left[\begin{array}{c|c} \phi_1^A & 0 \\ \hline 0 & \phi_2^A \end{array}\right] \\ \underbrace{\begin{array}{cc} n_1 & n_2 \end{array}}_{n} \end{array} \begin{array}{c} n_1^A \\ n_2^A \\ \end{array} \tag{20b}$$

$$\underset{(n_1^A+n_2^A)\times(n_1^A+n_2^A)}{[k_{CPL}]} = \begin{array}{c} \left[\begin{array}{c|c} k_{CPL}^{11} & k_{CPL}^{12} \\ \hline k_{CPL}^{21} & k_{CPL}^{22} \end{array}\right] \\ \begin{array}{cc} n_1^A & n_2^A \end{array} \end{array} \begin{array}{c} n_1^A \\ n_2^A \\ \end{array} \tag{20c}$$

and the final form of $[K]$ in Eq. (17) may be expressed as

$$\underset{n \times n}{[K]} = \underset{n \times n}{\left[\begin{array}{c|c} \omega_1^2 & 0 \\ \hline 0 & \omega_2^2 \end{array}\right]} + \underset{n \times n}{[\Phi^A]^T [k_{CPL}] [\Phi^A]} \tag{21}$$

2.2 DYNAMIC TRANSFORMATION

As a result of omitting the higher substructure modes, the solutions from the truncated Eq. (16) will have errors introduced. The truncation errors can be greatly diminished by including the modes that would have been truncated through a dynamic transformation. Instead of truncating or omitting modes, all modes can be included through a transformation that relates the "reduced" modes not contained explicitly in the solution to the modes that are "kept." If Ω_i^2 corresponds to an exact eigenvalue of Eq. (16), the relationship between the eigenvalue and its eigenvector may be expressed in terms of the kept, $\{q^k\}$, and reduced, $\{q^r\}$, coordinates as:

$$\underset{n\times n}{\Omega_i^2\,[I]}\ \underset{n\times 1}{\begin{Bmatrix} q^k \\ \hdashline q^r \end{Bmatrix}} = \underset{n\times n}{\left[\begin{array}{c|c} K^{kk} & K^{kr} \\ \hline K^{rk} & K^{rr} \end{array}\right]}\ \underset{n\times 1}{\begin{Bmatrix} q^k \\ \hdashline q^r \end{Bmatrix}} \tag{22}$$

where the $\{q^r\}$ corresponds to those modes previously truncated. If we designate n_k as the total number of modes kept from all the substructures and n_r as the total number of modes reduced, then

$$n = n_k + n_r \tag{23}$$

Expanding Eq. (22) into two equations for some general frequency, $p^2 = \Omega_i^2$, yields

$$\underset{n_k\times 1}{p^2\{q^k\}} = \underset{n_k\times n_k}{[K^{kk}]}\underset{n_k\times 1}{\{q^k\}} + \underset{n_k\times n_r}{[K^{kr}]}\underset{n_r\times 1}{\{q^r\}} \tag{24a}$$

$$\underset{n_r\times 1}{p^2\{q^r\}} = \underset{n_r\times n_k}{[K^{rk}]}\underset{n_k\times 1}{\{q^k\}} + \underset{n_r\times n_r}{[K^{rr}]}\underset{n_r\times 1}{\{q^r\}} \tag{24b}$$

Solving Eq. (24b) for $\{q^r\}$ in terms of $\{q^k\}$ gives

$$\underset{n_r \times 1}{\{q^r\}} = \underset{n_r \times n_k}{[R]}\underset{n_k \times 1}{\{q^k\}} \tag{25}$$

where

$$\underset{n_r \times n_k}{[R]} = -\underset{n_r \times n_r}{[K^{rr} - p^2 I]^{-1}}\underset{n_r \times n_k}{[K^{rk}]} \tag{26}$$

Using Eq. (25) for some "reduction frequency", p , we can write

$$\underset{n \times 1}{\left\{\begin{array}{c} q^k \\ \hdashline q^r \end{array}\right\}} = \underset{n \times 1}{\left\{\begin{array}{c} q^k \\ \hdashline R q^k \end{array}\right\}} = \underset{n \times n_k}{\left[\begin{array}{c} I \\ \hdashline R \end{array}\right]}\underset{n_k \times 1}{\{q^k\}} \tag{27}$$

The dynamic transformation matrix, $[T]$, is then defined as

$$\underset{n \times n_k}{[T]} = \underset{n \times n_k}{\left[\begin{array}{c} I \\ \hdashline R \end{array}\right]} \tag{28}$$

The reduced equation of motion is obtained directly by substituting the coordinate transformation

$$\underset{n \times 1}{\{q\}} = \underset{n \times n_k}{[T]}\underset{n_k \times 1}{\{q^k\}} \tag{29}$$

into Eq. (16) and pre-multiplying by the transpose of $[T]$. The reduced generalized mass and stiffness matrices can be written in the partitioned forms given by Eqs. (22) and (28):

$$\underset{n_k \times n_k}{[M^k]} = \underset{n_k \times n_k}{[I]} + \underset{n_k \times n_r}{[R]^T}\underset{n_r \times n_k}{[R]} \tag{30a}$$

$$\underset{n_k \times n_k}{[K^k]} = \underset{n_k \times n_k}{[K^{kk}]} + 2\underset{n_k \times n_r}{[K^{kr}]}\underset{n_r \times n_k}{[R]} + \underset{n_k \times n_r}{[R]^T}\underset{n_r \times n_r}{[K^{rr}]}\underset{n_r \times n_k}{[R]} \tag{30b}$$

Conventional methods of determining eigenvalues may be applied to the reduced equation of motion to obtain a set of eigenvalues, $\lceil \Omega^k \rfloor$, and a corresponding set of mass normalized eigenvectors, $[\gamma^k]$. From the coordinate relationship defined by Eq. (25), the reduced eigenvectors, $[\gamma^r]$, corresponding to the $\{q^r\}$ reduced coordinates are given by

$$\underset{n_r \times n_k}{[\gamma^r]} = \underset{n_r \times n_k}{[R]} \underset{n_k \times n_k}{[\gamma^k]} \tag{31}$$

where

$$[\gamma^{kr}] = \begin{array}{c} \left[\begin{array}{c} \gamma^k \\ \hline \gamma^r \end{array}\right] \end{array} \begin{array}{l} n_k \\ n_r \end{array} \tag{32}$$

and the physical eigenvectors for the total solution will be given by

$$\underset{n \times n_k}{[\Phi_x]} = \underset{n \times n}{[\phi]} \underset{n \times n_k}{[\gamma^{kr}]} \tag{33}$$

This solution will be exact for any Ω_i^k which is the same as the reduction frequency, p, used in developing $[T]$.

Significant improvement can be obtained in the modes and frequencies by applying the Rayleigh-Ritz method in conjunction with the dynamic transformation for individual modes. This part of the dynamic transformation will be referred to as backsubstitution. For each Ω_i^k to be considered, a revised mode shape, $[\bar{\gamma}_i^{kr}]$, can be determined by substituting $p = \Omega_i^k$ in $[R]$ and mass normalizing the mode shape:

$$[\gamma_i^r] = [R_i][\gamma_i^k] \tag{34a}$$

$$a_i = [\gamma_i^{kr}]^T[\gamma_i^{kr}] \tag{34b}$$

$$NF_i = 1/\sqrt{a_i} \tag{34c}$$

$$[\bar{\gamma}_i^{kr}] = NF_i\,[\gamma_i^{kr}] \tag{34d}$$

where NF_i is the normalization factor used to mass normalize one γ_i for some Ω_i^k .

A new estimate of Ω_i^k will be given by

$$\bar{\Omega}_i^{k\,2} = [\bar{\gamma}_i^{kr}]^T[K][\bar{\gamma}_i^{kr}]$$

Another measure of the accuracy of the solution is provided by the change in the eigenvalues and is provided by the eigenvalue ratio defined as

$$\left(\bar{\Omega}_i^k / \Omega_i^k\right)^2 .$$

SECTION 3

PROGRAM ENTRY POINTS

In order to provide user flexibility and at the same time minimize computation of basic data changes, six major entry points have been established for DAMUS:

1. Basic substructure data entered, subsystem eigensolutions.
2. Coupling spring stiffness data entered and stiffness contributions calculated.
3. Selection of modes to be kept/reduced/truncated, generalized mass and stiffness matrices calculated.
4. p^2 value for dynamic transformation entered, eigensolution for system using the dynamic transformation.
5. Calculation of physical eigenvectors for total system.
6. Backsubstitution of selected modes from system solution.

Entry into the program is accomplished by designating a specific entry point (EP). Termination of the program is accomplished by designating the last EP the user desires to execute.

The Fig. 3-1 flow chart is included to show the general flow of the program. A corresponding flow chart showing the main Fortran subroutine called by the program may be found in Appendix B. The flow chart for input/output files required by the program at each EP is in Section 4. This flow chart corresponds in form to the one shown in Fig. 3-1.

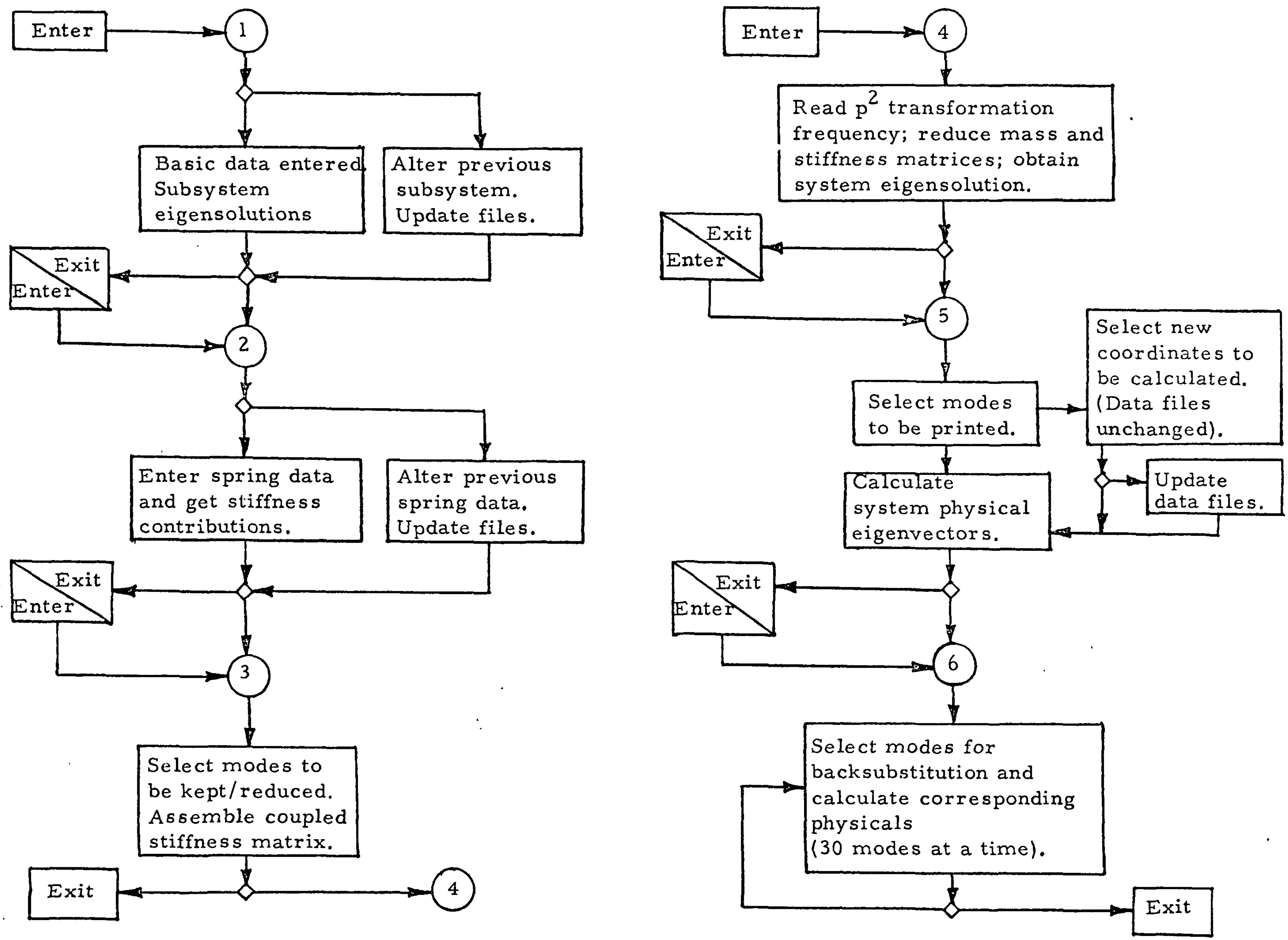


Figure 3-1. Program Flow Chart

A special vector input notation is used for reading in vectors used to select DOF orders. When it is required for the user to select a group of DOF's to be re-ordered or to designate a group of coordinates to be printed from a substructure, a vector of identifying DOF's is read into DAMUS by the READIM FORMA subroutine. The order in which the DOF numbers appear determines the particular sequence of DOF desired. If a sequential set of numbers from N1 to N2 is desired, the input may be abbreviated by the user. Inclusive groups of numbers to be generated in ascending order may be specified at any one time by using three elements of the input vector IV where

$$IV(I) = N1$$
$$IV(I+1) = 0$$
$$IV(I+2) = N2.$$

The integers from N1 to N2 will be sequentially expanded in the IV matrix starting from the IV(I) location. The last element of IV must be negative if this abbreviated form of input is used.

For an example, let us consider a substructure with 20 DOF's. It is desired to print only 10 of the substructure DOF's in a different order. The vector for reordering the DOF's would be designated as a 1 x 10 on the READIM header card. If the order to be printed is given as

7, 8, 9, 10, 2, 1, 15, 16, 17, 18

then the shortened input vector would be given by

7, 0, 10, 2, 1, 15, 0, -18.

If all the DOF's were desired to be printed in their original order, the input vector (1X20) would be

1, 0, -20

and the expanded vector of numbers 1 through 20 would be generated by the program.

Entry Point 1

The mass and stiffness matrices, $[m_i]$, $[k_i]$, for each substructure are read into DAMUS at EP-1. The substructures are defined in the program by a user supplied number which ranges from 1 to 20. Since each substructure is to be identified in the program by a distinct number, their input may be in any order. Input data for the mass matrix may be in two forms: an $n_i \times n_i$ square matrix or a $1 \times n_i$ row vector. Before solving the substructure eigenproblem, the attachment coordinates must be identified and partitioned into the x_i^A set. An input vector IDDOF is used here to specify the N_i^A coordinates. Since the special input notation as previously described is to be used, only the n_i^A coordinates need be specified. The program will complete the vector for re-arranging the mass and stiffness matrices. The n_i^A coordinates must be partitioned in the same order as the coupling-spring DOF's. If one substructure couples to several others, then each set of attachment DOF's must be specified in the order in which they will be used. For example, assume that substructure i couples to 3 other substructures. The x_i^A coordinates may then be partitioned as

$$\left\{ x_i^A \right\} = \left\{ \begin{matrix} x_i^{A1} \\ x_i^{A2} \\ x_i^{A3} \end{matrix} \right\} \begin{matrix} n_i^{A1} \\ n_i^{A2} \\ n_i^{A3} \end{matrix}$$

(If $x_i^{A1} = x_i^{A2}$, then only 2 partitions need to be specified). For EP-2, it will be necessary to input the n_i^{Aj} locations since each spring only couples 2 substructures at a time. Thus, there will be at most, 3 sets of ϕ_i^A associated with substructure i. After re-arranging the substructure DOF's, the complete vector will be printed out to allow the user to identify the substructure mode shapes. An additional input vector is required here to select which substructure DOF's are to be printed after the system is coupled. The DOF order desired refers to the original m_i, k_i, read into core, not the partitioned x_i^A, x_i^I coordinate set. If one desired all of the coordinates to be printed, the abbreviated vector ($1 \times n_i$) would be given by 1, 0, $-n_i$ in the READIM format. An option is included at this point to rotate the m_i, k_i into system coordinates by reading in a 3 x 3 direction cosine matrix. The substructure may not be rotated if its size is not divisible by three.

Another option for EP-1 is one for altering or adding substructure data. The user may add new substructures at any time. If a substructure or group of substructures need to be altered, only those to be changed can be entered. The program tapes will be updated to reflect the changes without regenerating previous unaltered substructural data.

Entry Point 2

Coupling spring stiffness data is entered here. Each coupling spring stiffness matrix is associated with only 2 substructures. The user must specify which two substructures are being coupled, the number of attachment DOF's associated with each substructure, and the starting location of the $n_i^{A\gamma}$ coordinates that were specified by the IDDOF vector in EP-1. The program then performs the product

$$[\Phi^A]^T [K_{CPL_i}] [\Phi^A]$$

and saves the result for assembly in EP-3 where the ϕ^A contains only those x_i^{Ai} coordinates corresponding to the K_{CPL_i} DOF's. As in EP-1, the user may add additional coupling springs corresponding to more substructures added. If a substructure was altered, this EP must be executed again to reflect the substructures' altered eigenvector. Only those coupling springs of direct concern need be calculated. The program will update the tapes without regenerating previous unaltered substructure data.

Entry Point 3

At this EP, the user specifies which modes are to be kept and reduced. The input matrix KEEP (2 x MAXSUB) is used where the column corresponds to a substructure. The (1, i) location specifies the total number of lowest modes kept for substructure i and the (2, i) row specifies the total number of next highest modes to be reduced. All other modes will be truncated. The restrictions for the total kept and reduced modes are given by

$$\sum_{i=1}^{MAXSUB} KEEP(1,i) \leq 100$$

$$\sum_{i=1}^{MAXSUB} KEEP(2,i) \leq 200$$

The generalized stiffness matrix is then assembled in its kept and reduced partitions. There must be at least 2 modes kept from each substructure read into DAMUS. For KEEP(1, i) = 10 and KEEP (2, i) = 20, the program will select modes 1 to 10 for the kept partition from substructure i and will place modes 11 to 30 in the reduced partition.

Entry Point 4

The reduction frequency, p , is entered at EP-4, and the dynamic transformation is applied to obtain the reduced mass and stiffness matrices. The eigenvalues for the coupled substructures are now obtained.

Entry Point 5

This entry point calculates the coupled physical eigenvectors* which are printed in substructure groups. The order in which they are to be printed is determined by the order the substructures were originally read into DAMUS. The user must specify how many modes are to be printed by specifying the first and last mode number of the group of modes desired. Considerable computer time may be saved by selecting coordinates and printing a few of the modes since only those selected will be calculated. The user may desire to re-enter the program to select new coordinates to be printed or more modes. If the option to obtain new coordinates is selected, the user must specify which substructures will be printed and a new identification vector for selecting the coordinates for each substructure being considered. When selecting only different modes to be printed, those coordinates previously defined in EP-1 will be used to calculate physicals. An option also exists for making the coordinate selection a permanent change and will cause the basic program tapes to be updated to reflect any new ordering specified by this entry point. The order in which the substructure groups will be printed may be altered this way.

*Referred to as "physicals" for convenience.

Entry Point 6

This EP is for backsubstitution. The user may select in any order up to 30 modes at a time to be backsubstituted. The same physicals as specified in EP-5 will be calculated and printed. If the program is entered here, it will use the system tapes previously generated and saved to calculate the physicals. For new coordinate selection in EP-5, the correct save tape must be used to obtain the physicals. If EP-6 is executed after EP-5 and a new coordinate selection was made, the physicals calculated will be those currently specified in EP-5. The new eigenvalues will be printed along with the normalization factor used to mass normalize the vectors and the frequency ratio $(\bar{\Omega}_i^k / \Omega_i^k)^2$ used as a measure of the frequency change.

SECTION 4

INPUT/OUTPUT DATA

4.1 INPUT DATA

This section describes the necessary input data required to execute DAMUS and is ordered by entry points. The data cards and the variables appearing on them are listed in sequential order with the input format or FORMA subroutine specified. The definitions for the variables specified on the cards are given to clarify their meaning.

Input Data for Starting Program

Card No.	Input Order	Format
1	IRUNNO, UNAME	(A6, 4X, 3A6)
2	TITLE 1	(12A6)
3	TITLE 2	(12A6)
4	FOD	(E10.0)
5	NTAPE(1), NTAPE(2),..., NTAPE(12)	(12I5)
6	IENTR, IEXIT	(2I5)

Definitions

IRUNNO	=	Run No.
UNAME	=	User's Name
TITLE 1	=	First Title
TITLE 2	=	Second Title
FOD	=	Final off-diagonal value for diagonalizing a matrix [A] using the method of Jacobi.
NTAPE(I)	=	Twelve tape and/or file units used by the program and assigned by the user. Only those tapes actually used must be specified.
IENTR	=	Entry Point for entering program. There are 6 entry points in all defined by the integers from 1 to 6. If the program is being entered at Entry Point 1 other than the first time, then IENTR = -1 must be specified.
IEXIT	=	Exit Point for terminating the program. The exit points are identical to the entry points with program termination occurring <u>after</u> the execution of the entry point specified by IEXIT.

4.1.1 Input Data - Entry Point 1

Card No.	Input Order	Format
1	NSUBS, IOP	(2I5)
2	ISUB, KEPMOD, MOPT, IROT	(4I5)
3	IDDOF (1XN1)	READIM
4	K (NXN)	READ
5	M (NXN) or (1XN)	READ
(6)*	RCOS (3X3)	READ
7	IPDOF (1XN2)	READIM

Cards 2 through 7 are repeated for each substructure defined.

Definitions

NSUBS	=	Number of substructures to be read into program at this time. There will be NSUBS sets of cards from 2-7 following Card 1.
IOP	=	0 denotes the first time the program is entered at Entry Point 1
	=	1 denotes more substructures are to be added to a set of substructures previously defined
	=	2 denotes one or more substructures from a previously defined set are to be changed.
ISUB	=	Substructure identification number which ranges from 1 to 20. Each substructure must be identified by a different no.
KEPMOD	=	Total number of modes to be saved on tape for substructure "ISUB." This number must not be less than the sum of the number of modes to "kept" plus the number of modes to be "reduced" for this particular substructure.

*( ) denotes optional input data and is not required if option is not exercised.

MOPT	=	1	Mass matrix is square NXN
	=	2	Diagonal mass matrix to be read in as a 1XN vector.
IROT	=	0	Substructure already in system coordinates. Delete Card 6 from input.
	=	1	Rotate substructure by direction cosines, a 3X3 matrix, read in on Card 6.

IDDOF	=	Special 1XN1 integer vector used to place connecting coordinates in first N1 DOF locations for "ISUB." Order of connecting DOF's must correspond to those used in coupling spring. The order in which the DOF's appear in IDDOF determines the re-arranged DOF order. N1 = the number of elements in IDDOF.
K	=	Input Stiffness Matrix, for "ISUB". (NXN)
M	=	Input Mass Matrix for "ISUB". (NXN) or (1XN)
RCOS	=	Optional Direction Cosines Matrix (3X3). Total number of substructure DOF's must be divisible by 3 in order to exercise this option.
IPDOF	=	Special 1XN2 integer vector used to select those physical coordinates to be calculated from "ISUB". The order in which the DOF's appear in IPDOF will determine the order in which they will be printed for substructure "ISUB." If no physical coordinates from "ISUB" are to be calculated, IPDOF(1) must equal zero. N2 equals the number of elements in IPDOF. All substructure DOF numbers refer to the original order in which they were read into the computer.

4.1.2 Input Data for Entry Point 2

Card No.	Input Order	Format
1	NCPLS, IOP	(2I5)
2	ISUB1, NROW1, NS1, ISUB2, NROW2, NS2	(6I5)
3	KCPL (NXN)	READ

Definitions

NCPLS	=	Number of coupling springs to be read into program at this time. There will be NCPLS sets of cards 2-3 following card 1.
IOP	=	0 denotes the first time the program is entered at Entry Point 2.
	=	1 denotes more coupling springs are to be added to a set of data previously generated
	=	2 denotes one or more coupling springs from a previously defined set are to be permanently changed.
ISUB1	=	First substructure coupled by spring (ISUB no.)
NROW1	=	Number of connecting DOF's in ISUB1 for this particular spring.
NS1	=	Starting DOF location of coordinates in ISUB1 which were ordered by IDDOF. The substructure may have more than one set of connecting coordinates. NS1 defines the reordered starting location for a connecting set of DOF's.
ISUB2	=	Second substructure coupled by spring ISUB2 must always be greater than ISUB1.
NROW2	=	Number of connecting DOF's in ISUB2 for this particular spring.
NS2	=	Starting DOF location of coordinates in ISUB2 which were ordered by IDDOF.
KCPL	=	Coupling spring stiffness matrix for coupling ISUB1 to ISUB2. DOF's for coupling spring are in same order as specified for the ISUB1, ISUB2 coordinates by IDDOF with the ISUB1 coordinates appearing first. N is the size of the total number of coordinates used from each substructure.

4.1.3 Input Data for Entry Point 3

Card No.	Input Order	Format
1	KEEP (2XMXSUB)	READIM

Definitions

KEEP = INTEGER Matrix defining how many modes are to be kept and reduced for all of the substructures. The KEEP(1, I) row defines the number of low modes to be kept for substructure I. The KEEP (2, I) row defines the number of modes to be reduced for substructure I. Modes from the substructures are arranged in ascending order by frequency. For some substructure ISUB, the first KEEP(1, ISUB) modes will be kept and the next KEEP(2, ISUB) modes will be reduced by the dynamic transformation.

MXSUB is the highest numbered substructure read into the program. A zero in some KEEP(2, ISUB) location will include all modes in the kept set.

4.1.4 Input Data for Entry Point 4

Card No.	Input Order	Format
1	LAMDAO (1X1)	READ

Definitions

LAMDAO = p^2 value used for the dynamic transformation for reduction.

4.1.5 Input Data for Entry Point 5

Card No.	Input Data	Format
1	MD1, MD2, IOP	(3I5)
(2)*	ID (1XN1)	READIM
(3)*	IPDOF (1XN2)	READIM

There will be N1 Card (3)'s.

Definitions

MD1	=	Mode number of first mode to be printed.
MD2	=	Mode number of last mode to be printed.
IOP	=	0 no optional cards needed
	=	1 requires cards (2) and (3), but data files not updated
		2 requires cards (2), (3) with permanent update of files.
ID	=	An integer vector containing N1 substructure ID's for which new physical DOF's are to be defined.
IPDOF	=	Ordering vector for selecting DOF's from each substructure defined by ID. There will be N1 of these cards.

*( ) Indicates optional data and is not required if option not exercised.

4.1.6 Input Data for Entry Point 6

Card No.	Input Data	Format
1	NBKSB	I5
2	IMODE (1XNMD)	READIM

Definitions

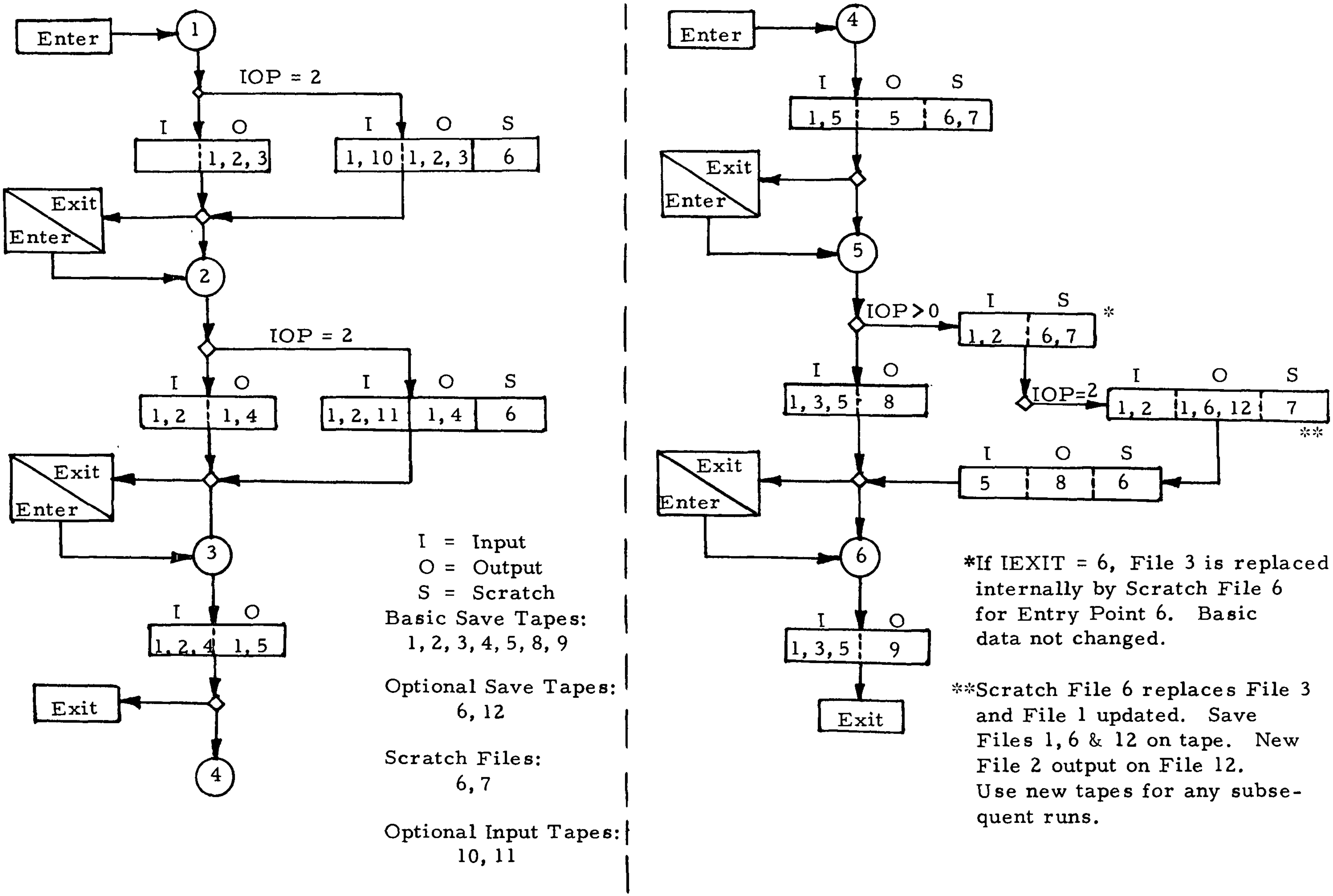
NBKSB = Number of groups of modes to be backsubstituted. 30 modes may be specified to be backsubstituted at any one time. NBKSB tells the program how many groups of 30 modes are to be selected.

IMODE = Integer vector selecting modes to be backsubstituted with NMD $\leq$ 30. There will be NBKSB card (2)'s.

4.2 OUTPUT FILES/TAPES

This section describes the data saved on each logical file. Figure 4-1 presents a Tape Flow Chart indicating which files will be required for executing the desired entry points. The program is written to handle files instead of tapes. A computer utility program should be used to save the necessary files on tape for re-entry into DAMUS. All eigenvalues and eigenvectors are output by subroutine WTAPDS and may be read by RTAPDS for use in another program.

Figure 4-1. Tape Flow Chart



4.2.1 Description of Output Files/Tapes (Ref. Fig. 4-1)

NTAPE(I)	Description
I	
1	This tape contains basic data necessary for program logic. It includes substructure sizes, ordering data, coupling indices, and data locations on the various tapes. It is required for every Entry Point (EP) and will be updated to reflect any changes due to option selections. It consists of one logical record written in binary by the standard Fortran WRITE routine.
2	This tape contains the eigenvalues and eigenvectors for each substructure. In addition, it has the identification vectors used to re-order the substructure DOF's for the initial solution and for printing physicals. This tape is output data from EP-1 and is used by EP-2, 3. If IOP = 2 for EP-5, this tape is needed as input. A new NTAPE(2) will be output on NTAPE(12) for subsequent runs.
3	This tape contains the partitioned set of substructure eigenvectors to be used in calculating physical vectors. Those DOF's to be calculated are packed into 100 DOF blocks and saved in the order read in. This is output from EP-1 and is required as input for EP-5 and EP-6, only if IOP = 0 for EP-5.
4	This tape contains the partitioned coupling spring data used for assembling the generalized stiffness matrix. The substructures are coupled 2 at a time. This tape is output from EP-2 and is required input for EP-3.
5	This tape contains the assembled generalized stiffness matrix in partitioned form plus the eigenvalues and participation factors from the system solution. Data is output from EP-3 and EP-4 on this tape and is required as input for EP-5 and EP-6. Re-entry into the program at EP's 3 and 4 will destroy previously generated data for that particular EP. If it is desired to save the previous data for some future reference, a new tape should be used; i.e., copy old tape data to new tape and use if data from EP-3 is needed.

NTAPE(I)	Description
I	
6	This is a scratch file. It is basically required only for EP-4. For particular options, it may be required for EP's 1, 2, 5, and 6. If IOP > 0 in EP-5, NTAPE(6) replaces NTAPE(3) for EP-5, 6. If IOP = 2 in EP-5, several files are updated permanently; and NTAPE(6) should be saved and used as NTAPE(3) for subsequent runs.
7	This is a scratch file required for EP-4. If IOP > 0 for EP-5, it is required there as a scratch file also.
8	This is an output tape containing only the system physical eigenvectors which are partitioned by substructure from EP-5.
9	This output tape contains those selected system eigenvalues and eigenvectors obtained for backsubstitution from EP-6.
10	Special input tape for EP-1 when IOP = 2. Use previous NTAPE(2) data and new NTAPE(2) generated. NTAPE(7) may be used here if old NTAPE(2) copied onto this file.
11	Special input tape for EP-2 when IOP = 2. Use previous NTAPE(4) data and new NTAPE(4) generated. NTAPE(7) may be used here if old NTAPE(4) data copied onto this file. If NTAPE(7) used in EP-1 for NTAPE(10), it may not be used again for EP-2 if the EP's are being executed consecutively.
12	Special output tape for EP-5 when IOP = 2. This tape replaces NTAPE(2) for subsequent runs.

4.2.2 Data Locations on Tapes

	Location	Matrix	
I			
1	1	--	Basic data
2	1	IDDOF	Vector for reordering substructure DOF's
	2	LAMDA	Substructure eigenvalues
	3	PHYSUB	Substructure eigenvectors
	4	IPDOF	Vector for selecting substructure DOF's to be printed in physicals.
	...		Set repeated for as many substructures read into program.
3	1	PHYPRT	Partitioned set of substructure vectors assembled by IPDOF.
	...		Repeated in blocks of 100 DOF until finished.
4	1	CPL11	Partitioned coupling spring, CPL.
	2	CPL22	
	3	CPL12	
	...		Set repeated for each spring read into program.
5	1	K22	Partitioned stiffness matrix for reduced coordinates
	2	K12-1	Partitioned stiffness matrix coupling terms
	3	K12-2	
	4	K11	Partitioned stiffness matrix for kept coordinates
	5	LAMSYS	System eigenvalues
	6	GAMK	Participation factors for kept coordinates
	7	GAMR11	Participation factors for reduced coordinates in partitioned form.
	8	GAMR12	
6	1	M*	Reduced mass matrix
	2	2K12*R11	Partitioned multiplications
	3	2K12*R12	
	4	K22*R11	
	5	K22*R12	

	Location	Matrix	
7	1	R11	R matrix for dynamic transformation in partitioned form.
	2	R12	
8	1	PHYSYS	System Eigenvectors
	...		One record for each substructure.
9	1	LAMBKS	Eigenvalues from backsubstitution
	2	PHYBKS	Eigenvectors from backsubstitution
	...		Repeat set for as many modes selected in groups of 30.
10		Optional input tape, NTAPE(2)	
11		Optional input tape, NTAPE(4)	
12		Optional output tape, NTAPE(2)	

APPENDIX A

FORTRAN LISTING OF DAMUS AND FLOW CHARTS

This appendix contains the Fortran listing of DAMUS. The main program has been divided into four links with each link beginning with one of the six entry points. The main program calls the first link with all links being called in sequential order.

Link No.	Entry Point	Subroutine Name
1	1	STC1
2	2	STC2
3	4	STC4
4	6	STC6

The flow chart following the program listing shows the major subroutines called by the main program links. If the subroutine called requires input data, a flow chart for that particular subroutine has been included.

```
01   06-06-73   15.547        STC MAIN LINK

      CSTC                   STC MAIN LINK
             COMMON IENTR,IEXIT,FOD,NUT1,NUT2,NUT3,NUT4,NUT5,NUT6,NUT7,NUT8
            1,            NUT9,NUT10,NUT11,NUT12
             COMMON /NLINEZ/ DUMY1 /LSTART/ DUMY2(30)
             COMMON /WORKVC/ LNGTHW,W(200)
             LNGTHW = 200
             CALL LINK   (5HENTRY1)
             STOP
             END

23747 WORDS OF MEMORY USED BY THIS COMPILATION
```

```
CSTC1          STIFFNESS COUPLING  ENTRY 1
      SUBROUTINE STC1
      DIMENSION A(100,100),S(100,100),PHY(100,100)
     1,          ID(100),IV(100),JV(100),T1(100),T2(100),T3(100)
     2,          NNDOF(20,6),KEEP(2,20),KCPL(210),KSK(20),KSR(20)
     3,          IDPHY(21),IDCPL(100),PHD(20)
      COMMON IENTR,IEXIT,FOD,NUT1,NUT2,NUT3,NUT4,NUT5,NUT6,NUT7,NUT8
     1,             NUT9,NUT10,NUT11,NUT12
      COMMON /NLINEZ/ DUMY1 /LSTART/ DUMY2(30)
      COMMON /WORKVC/ LNGTHW,W(200)
      DATA KD1,KD2,KD3,KD4,KD5,KD6,KD7,KD8/100,200,2,20,300,21,6,100/
      DATA LL1,LL2,LL3,LL4,LL5,LL6,LL7,LL9,LL10,LL11,LL12/11*1000/
      DATA PHD(1)/120HPHY1  PHY2  PHY3  PHY4  PHY5  PHY6  PHY7  PHY8  PH
     $Y9  PHY10 PHY11 PHY12 PHY13 PHY14 PHY15 PHY16 PHY17 PHY18 PHY19 PH
     $Y20 /
      DATA NSUBT,NCPLT,NNDOF,IDPHY,IDCPL,KCPL,KEEP,KSK,KSR/533*0/
 1000 FORMAT (16I5)
 1001 FORMAT (E10.0)
 2000 FORMAT (///10X'FOD =',1PE12.4)
 2001 FORMAT (///10X17HINPUT TAPE NOS. =,12I5,/10X17HUNIT ASSIGNED   =
     1,             12I5)
 2002 FORMAT (///10X'IENTR ='I5,10X'IEXIT ='I5)
 2003 FORMAT (///10X'ENTRY POINT'I5,4X'HAS BEEN COMPLETED.')
 2004 FORMAT (///10X'IENTRY ='I5,10X'NSUBS ='I5,10X'IOP ='I5)
C
 1    CALL START
      READ  (5,1001) FOD
      READ  (5,1000) NUT8,NUT1,NUT6,NUT2,NUT3,NUT4,NUT5,NUT7,NUT9
     1,             NUT10,NUT11,NUT12
      READ  (5,1000) IENTR,IEXIT
      WRITE (6,2000) FOD
      WRITE (6,2001) (I,I=1,12),NUT8,NUT1,NUT6,NUT2,NUT3,NUT4,NUT5,NUT7
     1,             NUT9,NUT10,NUT11,NUT12
      WRITE (6,2002) IENTR,IEXIT
      IF (IENTR.GT.1) GO TO 9002
      IF (IENTR.EQ.1) GO TO 9001
      REWIND NUT8
      READ  (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,             KSR,N,M,M1,M2,M1P1,NSYM,MSYM
C
 9001             IENTRY = 1
C
C  GET SUBSTRUCTURE MODAL DATA FROM MASS AND STIFFNESS MATRICES
C
      READ (5,1000) NSUBS,IOP
      CALL PAGEHD
      WRITE (6,2004) IENTRY,NSUBS,IOP
      IF (IOP.EQ.2) GO TO 120
      CALL SUBDAT (IOP,A,S,PHY,NNDOF,IDPHY,ID,IV,JV,T1,T2,T3
     1,             NSUBS,NSUBT,KD1,KD4,KD1,KD6,LL1,NUT1,LL6,NUT6,FOD,PHD)
      GO TO 123
  120 NSUBT = 0
```

```
      CALL SUBDAT (IOP,A,S,PHY,NNDOF,IDPHY,ID,IV,JV,T1,T2,T3
     1,           NSUBS,NSUBT,KD1,KD4,KD1,KD6,LL4,NUT4,0,0,FOD,PHD)
      CALL DELSUB (A,PHY,NNDOF,IDPHY,ID,IV,JV,NSUBS,NSUBT,KD1,KD2,KD7,4
     1,           LL1,NUT1,LL6,NUT6,LL10,NUT10,LL4,NUT4,NUT8)
  125 REWIND NUT8
      WRITE (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,           KSR,N,M,M1,M2,M1P1,NSYM,MSYM
      CALL EOF3   (LL1,NUT1,LL6,NUT6,LL8,NUT8)
      CALL PRINTI (31HSUBSTRUCTURES READ INTO PROGRAM,6,NNDOF(1,6)
     1,           1,NSUBT,1,0)
      IF (IEXIT.EQ.IENTRY) GO TO 9990
C
 9002 CALL LINK   (6HENTRY2)
C
 9990 CALL PAGEHD
      WRITE (6,2003) IENTRY
      STOP
      END
```

WORDS OF MEMORY USED BY THIS COMPILATION

```
CSTC2            STC2
      SUBROUTINE STC2
      DIMENSION A(100,100),S(100,100),PHY(100,100)
     1,            S12(100,200),SS(20100)
     2,            IV(100),JV(100),KKPT(100,2),KRED(100,2),MRED(2),MKPT(2)
     3,            NNDOF(20,6),KEEP(2,20),KCPL(210),KSK(20),KSR(20)
     4,            IDPHY(21),IDCPL(100)
      COMMON IENTR,IEXIT,FOD,NUT1,NUT2,NUT3,NUT4,NUT5,NUT6,NUT7,NUT8
     1,             NUT9,NUT10,NUT11,NUT12
      COMMON /ULINEZ/ DUMY1 /LSTART/ DUMY2(30)
      COMMON /WORKVC/ LNGTHW,W(200)
      EQUIVALENCE (SS(1),S(1,1)),(SS(1),S12(1,1)),(SS(10001),PHY(1,1))
      DATA KD1,KD2,KD3,KD4,KD5,KD6,KD7,KD8/100,200,2,20,300,21,6,100/
      DATA LL1,LL2,LL3,LL4,LL5,LL6,LL7,LL9,LL10,LL11,LL12/11*1000/
 1000 FORMAT (16I5)
 2003 FORMAT (///10X'ENTRY POINT'I5,4X'HAS BEEN COMPLETED.')
 2006 FORMAT (///10X'IENTRY ='I5,10X'NCPLS ='I5,10X'IOP ='I5)
 2007 FORMAT (///10X'IENTRY ='I5)
      REWIND NUT8
      READ  (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1             KSR,N,M,M1,M2,M,P1,NSYM,MSYM
      GO TO (9002,9002,9003,9004,9004,9004), IENTR
C
 9002              IENTRY = 2
C
C  GET INDIVIDUAL K* CONTRIBUTIONS FROM COUPLING SPRINGS
C
      READ (5,1000) NCPLS,IOP
      CALL PAGEHD
      WRITE (6,2006) IENTRY,NCPLS,IOP
      IF (IOP.EQ.2) GO TO 210
      CALL CPLSPG (A,S,PHY,NNDOF,KCPL,IDCPL,NCPLS,NCPLT,KD1,KD1,KD4
     1,            LL2,NUT2,LL1,NUT1)
      IF (IEXIT.EQ.IENTRY .OR. IOP.EQ.1) GO TO 220
      GO TO 230
  210 NCPLT = 0
      CALL CPLSPG (A,S,PHY,NNDOF,KCPL,IDCPL,NCPLS,NCPLT,KD1,KD1,KD4
     1,            LL4,NUT4,LL1,NUT1)
      CALL DELCPL (A,NNDOF,IDCPL,KCPL,IV,NCPLS,NCPLT,KD1,KD2,KD7,KD8,KD
     1,            LL2,NUT2,LL11,NUT11,LL4,NUT4,NUT8)
  220 REWIND NUT8
      WRITE (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1             KSR,N,M,M1,M2,M,P1,NSYM,MSYM
      CALL EOF3    (LL8,NUT8,0,0,0,0)
  230 CONTINUE
      CALL EOF3    (LL2,NUT2,0,0,0,0)
      CALL CNNCTV (A,NNDOF,KCPL,KD4,KD1,KD4)
      IF (IEXIT.EQ.IENTRY) GO TO 9990
C
 9003              IENTRY = 3
C
C  K* ASSEMBLY
```

```
C
      CALL PAGEHD
      WRITE (6,2007) IENTRY
      CALL READIM (KEEP,NR,MXSUB,KD3,KD4)
      CALL INDCES (KEEP,MXSUB,KSK,KSR,N,M,NSM1,M1,M2,M1P1,NSYM,MSYM,KD3)
      REWIND NUT8
      WRITE (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,             KSR,N,M,M1,M2,M1P1,NSYM,MSYM
      CALL EOF3    (LL8,NUT8,0,0,0,0)
C
C  ASSEMBLE K22*
C
      CALL ASMBL1 (2,SS,A,KRED,MRED,KEEP,NNDOF,KSR,KCPL,IV,JV,M,MXSUB
     1,            NSM1,MSYM,KD1,KD3,KD4,1,LL3,NUT3,LL2,NUT2,LL1,NUT1)
C
C  ASSEMBLE K12*
C
      CALL ASMBL2 (S12,A,KKPT,MKPT,KRED,MRED,KEEP,KSK,KSR,KCPL,IV,JV,N,M
     1,            M1,M2,M1P1,MXSUB,NSM1,KD1,KD3,2,LL3,NUT3,LL2,NUT2)
C
C  ASSEMBLE K11*
C
      CALL ASMBL1 (1,SS,A,KKPT,MKPT,KEEP,NNDOF,KSK,KCPL,IV,JV,N,MXSUB
     1,            NSM1,NSYM,KD1,KD3,KD4,4,LL3,NUT3,LL2,NUT2,LL1,NUT1)
      CALL EOF3    (LL3,NUT3,0,0,0,0)
      IF (IEXIT.EQ.IENTRY) GO TO 9990
C
 9004 CALL LINK    (6HENTRY4)
C
 9990 CALL PAGEHD
      WRITE (6,2003) IENTRY
      STOP
      END
```

WORDS OF MEMORY USED BY THIS COMPILATION

```
CSTC4           STIFFNESS COUPLING  ENTRY 4
      SUBROUTINE STC4
      DIMENSION A(100,100),S(100,100),PHY(100,100),S12(100,200)
     1,          S21(200,100),R(200,50),R2(200,50),SS(20100)
     2,          ID(100),IV(100),JV(100),T1(100),T2(100),T3(100)
     3,          NNDOF(20,6),KEEP(2,20),KCPL(210),KSK(20),KSR(20)
     4,          IDPHY(21),IDCPL(100),PHD(20)
     5,          LAMSYS(100)
      COMMON IENTR,IEXIT,FOD,NUT1,NUT2,NUT3,NUT4,NUT5,NUT6,NUT7,NUT8
     1,             NUT9,NUT10,NUT11,NUT12
      COMMON /NLINEZ/ DUMY1 /LSTART/ DUMY2(30)
      COMMON /WORKVC/ LNGTHW,W(200)
      EQUIVALENCE (SS(1),S(1,1)),(SS(1),S12(1,1)),(SS(1),S21(1,1))
     1,          (A(1,1),R(1,1))
     2,          (SS(10001),PHY(1,1)),(SS(10001),R2(1,1))
      REAL LAMSYS,LAMDAO
      DATA KD1,KD2,KD3,KD4,KD5,KD6,KD7,KD8/100,200,2,20,300,21,6,100/
      DATA LL1,LL2,LL3,LL4,LL5,LL6,LL7,LL9,LL10,LL11,LL12/11*1000/
      DATA PHD(1)/120HPHY1  PHY2  PHY3  PHY4  PHY5  PHY6  PHY7  PHY8  PH
     $Y9  PHY10 PHY11 PHY12 PHY13 PHY14 PHY15 PHY16 PHY17 PHY18 PHY19 PH
     $Y20 /
 1000 FORMAT (16I5)
 2003 FORMAT (///10X'ENTRY POINT'I5,4X'HAS BEEN COMPLETED.')
 2005 FORMAT (///10X'IENTRY ='I5,10X'MD1 ='I5,10X'MD2 ='I5,10X'IOP ='I5)
 2007 FORMAT (///10X'IENTRY ='I5)
      REWIND NUT8
      READ  (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,            KSR,N,M,M1,M2,M1P1,NSYM,MSYM
      GO TO (9004,9004,9004,9004,9005,9006), IENTR
C
 9004            IENTRY = 4
C
C   FORM R FOR DYNAMIC TRANSFORMATION
C
      CALL PAGEHD
      WRITE (6,2007) IENTRY
      CALL READ   (LAMDAO,NR,NC,1,1)
      CALL RTAPSS (SS,NR,NC,ANM,1,LL3,NUT3)
      CALL RMAT   (SS,R,LAMDAO,M,KD2,1,LL5,NUT5,2,LL3,NUT3)
C
C  M*
C
      CALL MSTAR  (A,S21,N,M,M1P1,KD1,KD2,1,LL4,NUT4,1,LL5,NUT5)
C
C  K*
C
      CALL KSTAR  (S12,R,SS,S,A,R2,N,M,M1P1,KD1,KD2,2,LL4,NUT4
     1,           2,LL3,NUT3,1,LL5,NUT5,1,LL3,NUT3)
C
C  SOLVE FOR EIGENVALUES AND EIGENVECTORS
C
      CALL EIGVEC (A,S,S21,LAMSYS,T2,T3,N,M,M1,M2,M1P1,KD1,KD2
```

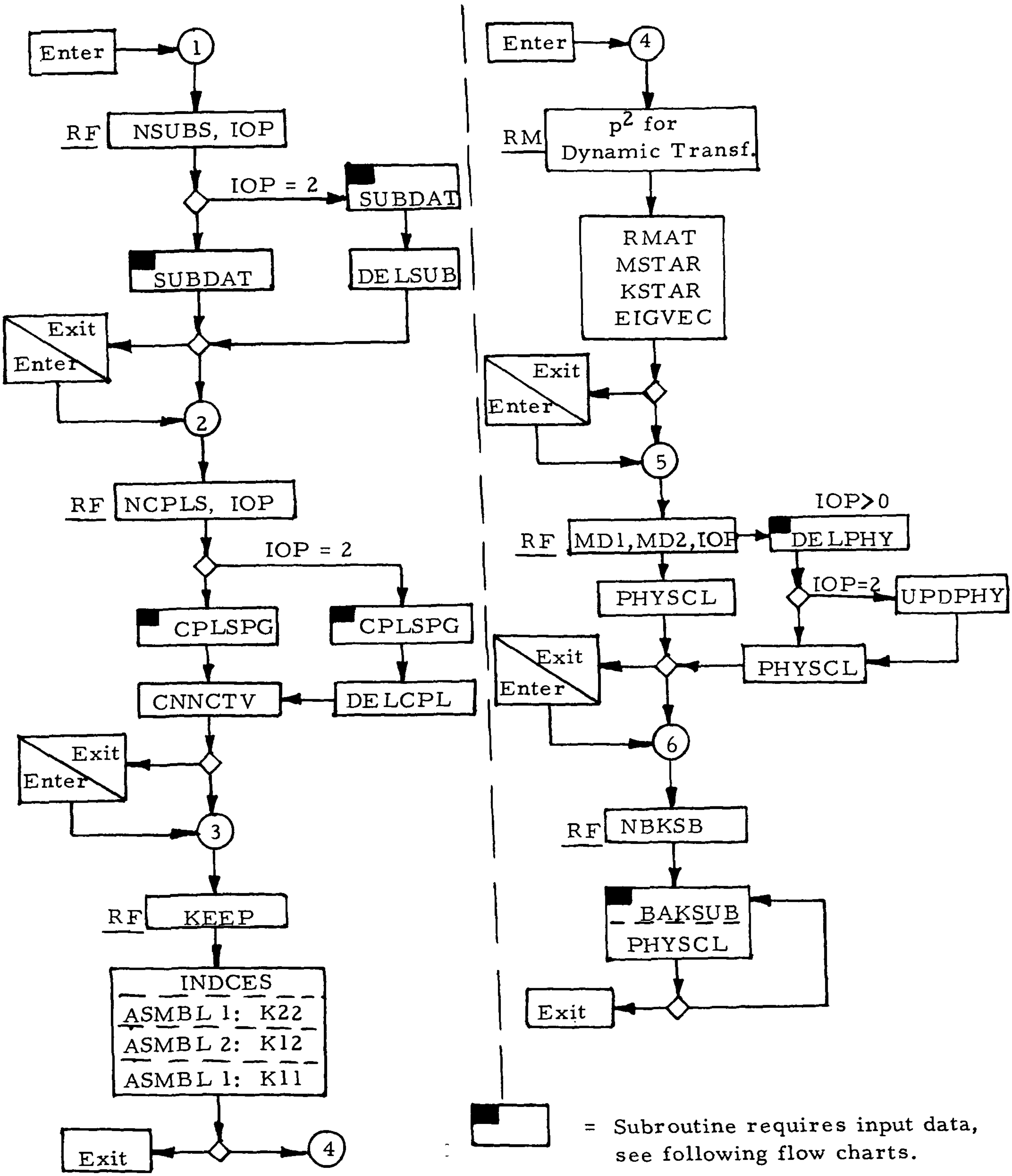
```
     1,              5,LL3,NUT3,1,LL4,NUT4,1,LL5,NUT5,FOD)
      CALL EOF3      (LL3,NUT3,0,0,0,0)
      IF (IEXIT.EQ.IENTRY) GO TO 9990
C
 9005                IENTRY = 5
C
      READ  (5,1000) MD1,MD2,IOP
      CALL PAGEHD
      WRITE (6,2005) IENTRY,MD1,MD2,IOP
      IF (IOP.EQ.0) GO TO 520
      CALL DELPHY (A,PHY,NNDOF,IDPHY,T1,ID,IV,JV,NSUBS,KD1,KD4,KD6
     1,              LL4,NUT4,LL5,NUT5,LL1,NUT1)
      IF (IOP.EQ.1) GO TO 510
      CALL UPDPHY (A,NNDOF,JV,NSUBS,NSUBT,KD1,KD4,LL12,NUT12,LL1,NUT1
     1,              LL5,NUT5)
      REWIND NUT8
      WRITE (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,              KSR,N,M,M1,M2,M1P1,NSYM,MSYM
      CALL EOF3      (LL4,NUT4,LL8,NUT8,LL12,NUT12)
 510  LL6  = LL4
      NUT6 = NUT4
C
C  GET PHYSICALS
C
 520  CONTINUE
      CALL PHYSCL (PHY,S,A,R,NNDOF,KEEP,KSK,KSR,IDPHY,N,MD1,MD2,KD1
     1,              KD2,KD4,KD3,KD6,1,LL7,NUT7,6,LL3,NUT3,LL6,NUT6,PHD)
      CALL EOF3      (LL7,NUT7,0,0,0,0)
      IF (IEXIT.EQ.IENTRY) GO TO 9990
C
 9006 CALL LINK   (6HENTRY6)
C
 9990 CALL PAGEHD
      WRITE (6,2003) IENTRY
      STOP
      END

WORDS OF MEMORY USED BY THIS COMPILATION
```

6-06-73 15.562 STC6

```
CSTC6               STC6
      SUBROUTINE STC6
      DIMENSION A(100,100),S(100,100),PHY(100,100),S12(100,200)
     1,              S21(200,100),GAMA(300,30),SS(20100)
     2,              ID(100),IV(100),JV(100),T1(100),T2(100),T3(100)
     3,              NNDOF(20,6),KEEP(2,20),KCPL(210),KSK(20),KSR(20)
     4,              IDPHY(21),IDCPL(100),PHD(20)
     5,              LAMSYS(100)
      COMMON IENTR,IEXIT,FOD,NUT1,NUT2,NUT3,NUT4,NUT5,NUT6,NUT7,NUT8
     1,                NUT9,NUT10,NUT11,NUT12
      COMMON /NLINEZ/ DUMY1 /LSTART/ DUMY2(30)
      COMMON /WORKVC/ LNGTHW,W(200)
      EQUIVALENCE (SS(1),S(1,1)),(SS(1),S12(1,1)),(SS(1),S21(1,1))
     1,              (A(1,1),GAMA(1,1))
     2,              (SS(10001),PHY(1,1))
      REAL LAMSYS
      DATA KD1,KD2,KD3,KD4,KD5,KD6,KD7,KD8/100,200,2,20,300,21,6,100/
      DATA LL1,LL2,LL3,LL4,LL5,LL6,LL7,LL9,LL10,LL11,LL12/11*1000/
      DATA PHD(1)/120HPHY1   PHY2   PHY3   PHY4   PHY5   PHY6   PHY7   PHY8   PH
     $Y9   PHY10  PHY11  PHY12  PHY13  PHY14  PHY15  PHY16  PHY17  PHY18  PHY19  PH
     $Y20  /
 1000 FORMAT (16I5)
 2003 FORMAT (///10X'ENTRY POINT'I5,4X'HAS BEEN COMPLETED,')
 2008 FORMAT (///10X'IENTRY ='I5,10X'NBKSB ='I5)
      REWIND NUT9
      LL9 = 1
      REWIND NUT8
      READ  (NUT8) NSUBT,NNDOF,NCPLT,IDCPL,KCPL,IDPHY,KEEP,KSK
     1,            KSR,N,M,M1,M2,M1P1,NSYM,MSYM
C
 9006             IENTRY = 6
C
C   BACKSUBSTITUTION
C
      READ (5,1000) NBKSB
      CALL PAGEHD
      WRITE (6,2008) IENTRY,NBKSB
      CALL RTAPDS (LAMSYS,NR,NC,ANM,1,5,LL3,NUT3)
      DO 490 JJ=1,NBKSB
      CALL BAKSUB (GAMA,S12,S21,SS,S,LAMSYS,ID,IV,JV,T1,T2,T3,N,M,NMD
     1,            KD5,KD1,KD2,6,LL3,NUT3,2,LL3,NUT3,1,LL3,NUT3)
      CALL WTAPDS (T2,1,NMD,6HLAMBKS,1,LL9,LL9,NUT9)
      CALL PHYSCL (PHY,S,A,GAMA,NNDOF,KEEP,KSK,KSR,IDPHY,N,1,NMD
     1,            KD1,KD5,KD4,KD3,KD6,LL9,LL9,NUT9,0,0,0,LL6,NUT6,PHD)
  490 CONTINUE
      CALL EOF3   (LL9,NUT9,0,0,0,0)
 9990 CALL PAGEHD
      WRITE (6,2003) IENTRY
      STOP
      END
```

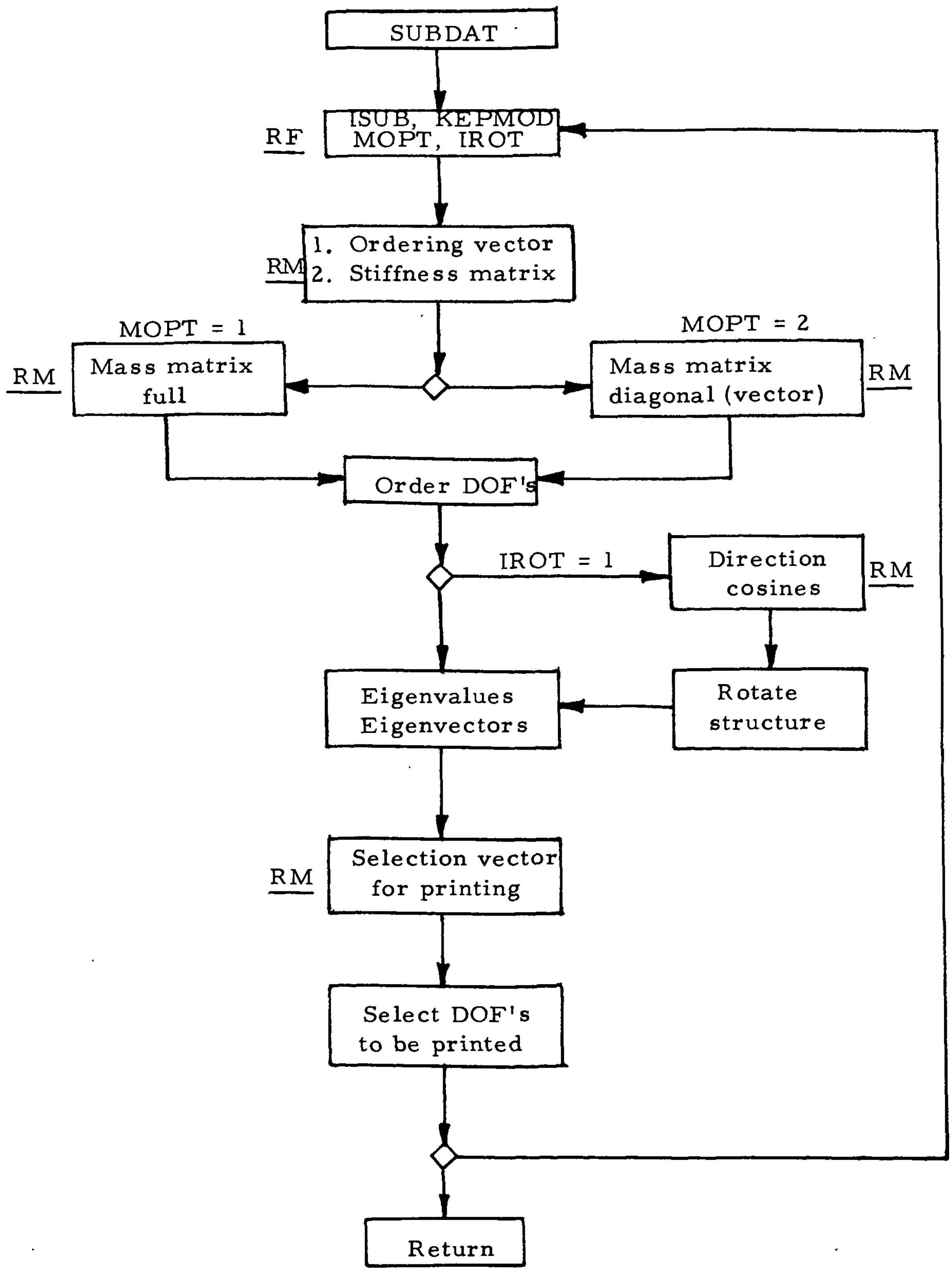
WORDS OF MEMORY USED BY THIS COMPILATION

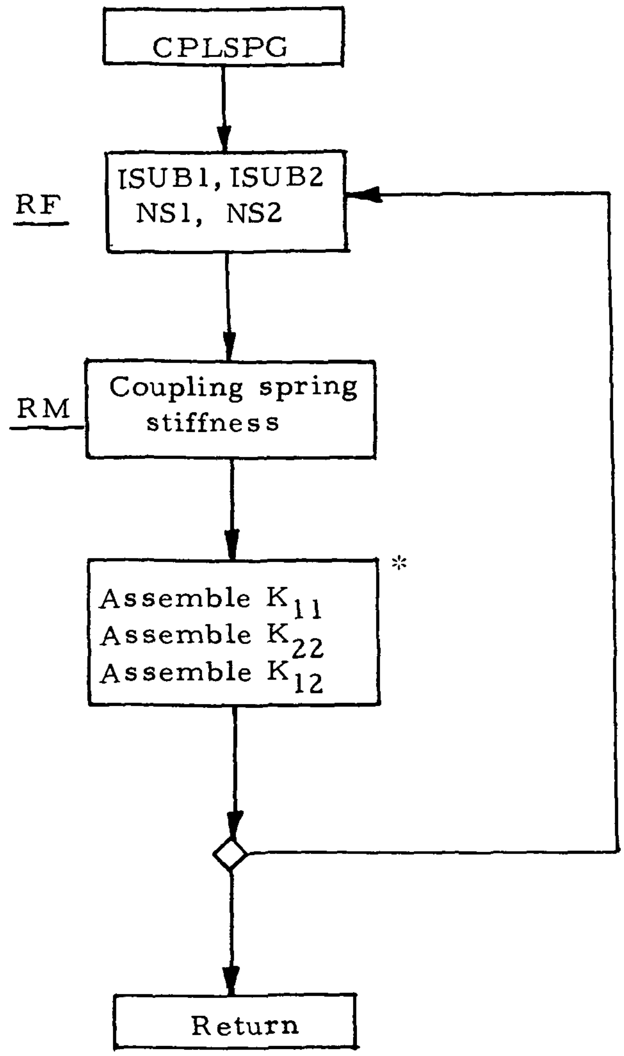


= Subroutine requires input data, see following flow charts.

RF = Read formatted input data.

RM = Read matrix data using FORMA routines.

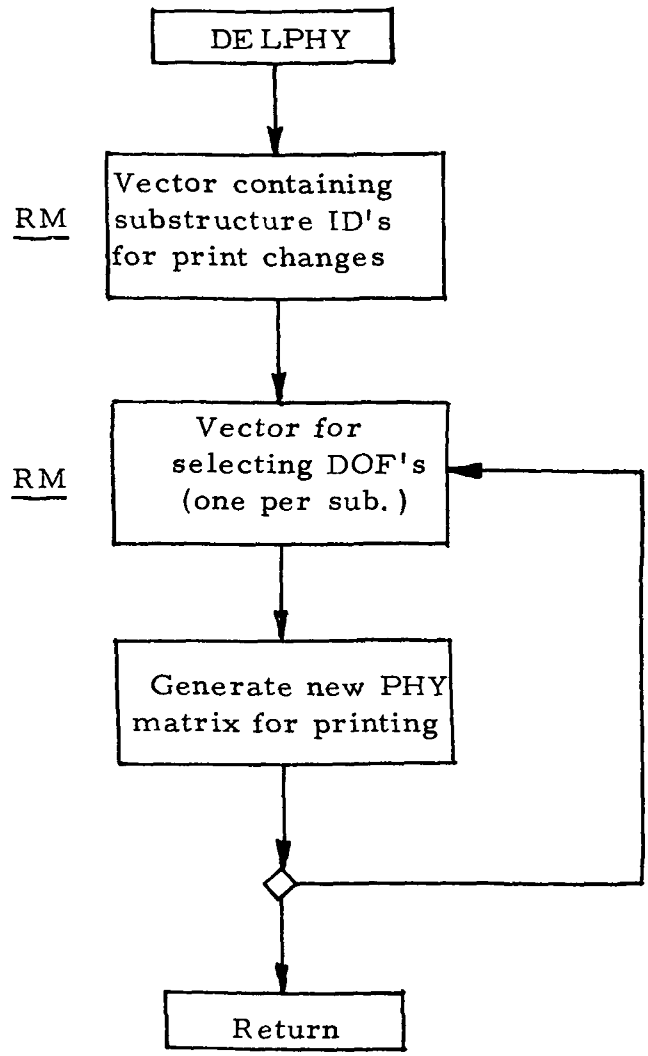

SUBDAT
RF
ISUB, KEPMOD
MOPT, IROT
RM
1. Ordering vector
2. Stiffness matrix
MOPT = 1
RM
Mass matrix
full
MOPT = 2
Mass matrix
diagonal (vector)
RM
Order DOF's
IROT = 1
Direction
cosines
RM
Eigenvalues
Eigenvectors
Rotate
structure
RM
Selection vector
for printing
Select DOF's
to be printed
Return

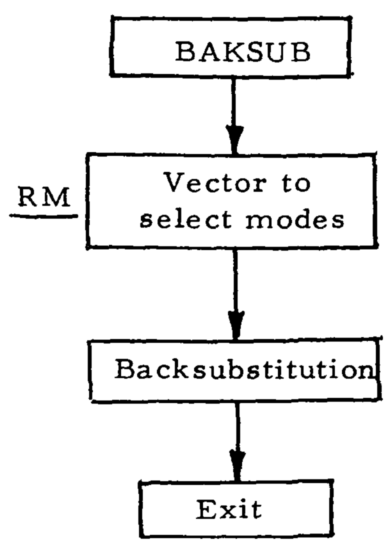


$$^{*}K_{11} = [\phi_1]^T [K_{CPL}][\phi_1]$$

$$K_{22} = [\phi_2]^T [K_{CPL}][\phi_2]$$

$$K_{12} = [\phi_1]^T [K_{CPL}][\phi_2]$$


DELPHY
RM
Vector containing substructure ID's for print changes
RM
Vector for selecting DOF's (one per sub.)
Generate new PHY matrix for printing
Return


BAKSUB
RM
Vector to select modes
Backsubstitution
Exit

APPENDIX B

SUBROUTINE EXPLANATIONS

This appendix contains a brief description of the subroutines specifically generated for DAMUS. Some of the subroutines may be used in a general FORMA program. The following list of general subroutines were used by DAMUS. Detailed explanations of each routine are contained in the subroutine comment cards.

Subroutine Names

ALPHAA	LTAPE	START
BTABA	MULTZ	SYMLH
BTABZ	NEGATS	TRANS
BTAZ	NEWMOD	WRITE
BTB	ORDER	WRITIM
COLMLT	PAGEHD	WTAPE
COPY	PRINT	ZERO
DCOM1	PRINTI	ZZBOMB
DIAG	READ	
EIGN1	READIM	
INTAPE	REVSYM	
INV4	RTAPE	

Subroutines for DAMUS

ADDLAM	Adds substructure eigenvalues to diagonal elements of single-subscripted, symmetrically stored matrix.
ASMBL1	Assembles K_{11}, K_{22} partitions in symmetric form.
ASMBL2	Assembles K_{12} partition, double subscripts
ASSEM1	Adds K_{CPL} contributions into correct locations of K_{11}, K_{22}.
ASSEM2	Adds K_{CPL} contributions into correct locations of K_{12}
BAKSUB	Backsubstitutes eigenvectors
BSOLVS	Solution for Z of equation $[A]\ [Z] = [B]$ where $[A]$ is symmetrically stored.
BTABSA	Matrix triple product $Z = B^T A B$ where A is symmetrically stored. Z is double-subscripted but only upper-half is returned.
CNNCTV	Calculate connectivity for substructures.
CPLSPG	Generates spring contributions of 2 substructures in partitioned form.
DCMSYM	Decomposes symmetrically stored matrix A into factors where $A = L D L^T$
DELCPL	Changes data files when changing a coupling spring
DELPHY	Changes data files when changing physical vectors to be printed
DELSUB	Changes data files when changing basic substructure data
EIGVEC	Gets eigenvalues and complete set of participation factors
EOF3	Write end of file for up to 3 files at a time
GETPHY	Used to generate substructure vector matrix for obtaining physicals

IDFILL	Special routine which fills up vector for omitted values
INDCES	Generates initial data and index locations
KEEPV	Generates vectors for assembling K matrix
KSTAR	Generates reduced stiffness matrix
MODE2	Eigenvalue/vector routine with mass matrix options
MSTAR	Generates reduced mass matrix
MULTBS	Multiplies BZ = A * BZ where A is symmetrically stored
NEWPHY	Generates new set of eigenvectors in partitioned form for getting physicals
PHYSCL	Calculates physical eigenvectors
REVAZZ	Revises matrix A into matrix Z, where Z may be a single or double subscripted matrix
RMAT	Calculates $[R]$ for dynamic transformation
ROTATA	Special triple product $Z = R^T A R$ when a 3X3 submatrix of direction cosines is input for R.
RTAPDS	Special matrix read tape routine - double subscript
RTAPSS	Special matrix read tape routine - single subscript
SUBDAT	Generates substructure eigenvalues and vectors from basic substructure mass and stiffness matrices
TRANSA	$B = A^T$ where A, B occupy the same core location
UNPAKS	Unpacks symmetric single-subscripted array into symmetric double subscripted storage (upper half only)
UPDFIL	Updates data from two files to one in a predescribed order
UPDPHY	Updates data file for physical vectors
WTAPDS	Special matrix write tape routine - double subscripts
WTAPSS	Special matrix write tape routine - single subscripts

APPENDIX C

SAMPLE PROBLEM

This appendix contains a sample problem using all 6 entry points of DAMUS.

The sample problem used to illustrate the use of DAMUS was Problem 1, a 20 DOF longitudinal rod model consisting of 2 substructures (10 DOF/substructure). The output data printed by DAMUS follows a listing of the actual data cards used to execute the program.

Since this was only a test case, no output tapes were saved and the same logical tape unit was assigned to the input files 7, 8 and 9. Normal execution of DAMUS would require different logical unit numbers.

INPUT DATA CARDS

```
SICA01     E.J. KUHAR
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD      2 SUBSTRUCTURES
 0.
   10   11   12   13   14   15   16   16   16
    1    6
    2
    1   10    2
IDDOF    1    1             ORDERS DOF'S FOR ATTACHMENT POINTS
    1    1   -1
0000000000
K1      10   10             STIFFNESS MATRIX
    1    1   2000.             -2000.
    2    1   -2000.             4000.            -2000.
    3    2   -2000.             4000.            -2000.
    4    3   -2000.             4000.            -2000.
    5    4   -2000.             4000.            -2000.
    6    5   -2000.             4000.            -2000.
    7    6   -2000.             4000.            -2000.
    8    7   -2000.             4000.            -2000.
    9    8.  -2000.             4000.            -2000.
   10    9   -2000.             6000.
0000000000
M1       1   10             MASS MATRIX
    1    1   1.                 1.               1.               1.
    1    5   1.                 1.               1.               1.
    1    9   1.                 1.
0000000000
IPDOF    1    3             SELECTS DOF TO BE PRINTED
    1    1    1     0   -10
0000000000
    2   10    2
IUDOF    1    1             ORDERS DOF'S FOR ATTACHMENT POINTS
    1    1   -1
0000000000
K2      10   10             STIFFNESS MATRIX
    1    1   2000.             -2000.
    2    1   -2000.             4000.            -2000.
    3    2   -2000.             4000.            -2000.
    4    3   -2000.             4000.            -2000.
```

EP-1

N. B. * In Column 71 cancels call to Forma subroutine PAGEHD.

```
     5    4   -2000.           4000.          -2000.
     6    5   -2000.           4000.          -2000.
     7    6   -2000.           4000.          -2000.
     8    7   -2000.           4000.          -2000.
     9    8   -2000.           4000.          -2000.
    10    9   -2000.           2000.
0000000000
M2        1   10             MASS.MATRIX
     1    1   1.               1.             1.             1.
     1    5   1.               1.             1.             1.
     1    9   1.               1.
0000000000
IPDOF     1    3             SELECTS DOF TO BE PRINTED
     1    1    1    0   -10
0000000000
     1
     1    1    1    2    1    1                                EP-2
KCPL      2    2             COUPLING SPRING STIFFNESS MATRIX
     1    1    2000.          -2000.
     2    1   -2000.           2000.
0000000000
KEEP      2    2             SELECTS KEPT/REDUCED DOF'S       EP-3
     1    1    2    2
     2    1    8    8
0000000000
LAMDA0    1    1             P**2  REDUCTION FREQUENCY        EP-4
     1    1   0.
0000000000
     1    4                                                   EP-5
     1
IMODE     1    4             SELECTS MODES FOR BACKSUBSTITUTION  EP-6
     1    1    1    0   -4
0000000000
```

```
                    TIME SHEET
        ------------------------------------------

        CURRENT TIME OF DAY          =     15.099317


FOD =  0.

INPUT TAPE NOS. =    1    2    3    4    5    6    7    8    9   10   11   12
UNIT ASSIGNED   =   10   11   12   13   14   15   16   16   16    0    0    0

IENTR =    1          IEXIT =    6
```

RUN NO. STCA01 DATE 053173 PAGE NO. 1
RUN BY F.J. KUHAR

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

IENTRY = 1 NSUBS = 2 IOP = 0

```
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD    2 SUBSTRUCTURES

ISUB =  1   KEPMOD =  10   MOPT =  2   IROT =  0

CARD INPUT INTEGER MATRIX IDDOF   (  1 X  1 )        ORDERS DOF'S FOR ATTACHMENT POINTS     0

  1   1  -1

END OF READIM.

CARD INPUT MATRIX K1   ( 10 X  10 )        STIFFNESS MATRIX     0

  1   1   2.00000000E 03  -2.00000000E 03   0.                    0.
  2   1  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  3   2  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  4   3  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  5   4  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  6   5  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  7   6  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  8   7  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  9   8  -2.00000000E 03   4.00000000E 03  -2.00000000E 03
 10   9  -2.00000000E 03   6.00000000E 03

END OF READ.

CARD INPUT MATRIX M1   (  1 X  10 )        MASS MATRIX     0

  1   1   1.00000000E 00   1.00000000E 00   1.00000000E 00   1.00000000E 00
  1   5   1.00000000E 00   1.00000000E 00   1.00000000E 00   1.00000000E 00
  1   9   1.00000000E 00   1.00000000E 00

END OF READ.
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

SUBSTRUCTURE 1 HAS 10 DOF WITH 1 BOUNDARY DOF DEFINED.

IDDOF DEFINES DOF ORDER

(1 X 10)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1	1	1	2	3	4	5	6	7	8	9	10									

RUN BY E.J. KUHAR

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

LAMBDA (EIGENVALUES)

(1 X 10)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	4.9247E 01	4.3597E 02	1.1716E 03	2.1840E 03	3.3743E 03	4.6257E 03	5.8160E 03	6.8284E 03	7.5640E 03	7.9508E 03

OMEGA (RAD/SEC)

(1 X 10)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	7.0176E 00	2.0880E 01	3.4228E 01	4.6734E 01	5.8088E 01	6.8013E 01	7.6262E 01	8.2634E 01	8.6971E 01	8.9167E 01

FREQ (HZ)

(1 X 10)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	1.1169E 00	3.3232E 00	5.4476E 00	7.4379E 00	9.2451E 00	1.0825E 01	1.2138E 01	1.3152E 01	1.3842E 01	1.4191E 01

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1

20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

PHY1

(10 X 10)		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	4.4583E-01	4.3486E-01	4.1317E-01	3.8131E-01	3.4006E-01	2.9044E-01	2.3367E-01	1.7114E-01	1.0440E-01	3.5088E-02
2	1	4.3486E-01	3.4006E-01	1.7114E-01	-3.5088E-02	-2.3367E-01	-3.8131E-01	-4.4583E-01	-4.1317E-01	-2.9044E-01	-1.0440E-01
3	1	4.1317E-01	1.7114E-01	-1.7114E-01	-4.1317E-01	-4.1317E-01	-1.7114E-01	1.7114E-01	4.1317E-01	4.1317E-01	1.7114E-01
4	1	3.8131E-01	-3.5088E-02	-4.1317E-01	-3.4006E-01	1.0440E-01	4.3486E-01	2.9044E-01	-1.7114E-01	-4.4583E-01	-2.3367E-01
5	1	3.4006E-01	-2.3367E-01	-4.1317E-01	1.0440E-01	4.4583E-01	3.5088E-02	-4.3486E-01	-1.7114E-01	3.8131E-01	2.9044E-01
6	1	2.9044E-01	-3.8131E-01	-1.7114E-01	4.3486E-01	3.5088E-02	-4.4583E-01	1.0440E-01	4.1317E-01	-2.3367E-01	-3.4006E-01
7	1	2.3367E-01	-4.4583E-01	1.7114E-01	2.9044E-01	-4.3486E-01	1.0440E-01	3.4006E-01	-4.1317E-01	3.5088E-02	3.8131E-01
8	1	1.7114E-01	-4.1317E-01	4.1317E-01	-1.7114E-01	-1.7114E-01	4.1317E-01	-4.1317E-01	1.7114E-01	1.7114E-01	-4.1317E-01
9	1	1.0440E-01	-2.9044E-01	4.1317E-01	-4.4583E-01	3.8131E-01	-2.3367E-01	3.5088E-02	1.7114E-01	-3.4006E-01	4.3486E-01
10	1	3.5088E-02	-1.0440E-01	1.7114E-01	-2.3367E-01	2.9044E-01	-3.4006E-01	3.8131E-01	-4.1317E-01	4.3486E-01	-4.4583E-01

```
         STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
         20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

CARD INPUT INTEGER MATRIX IPDOF   (   1 X   3 )          SELECTS DOF TO BE PRINTED              0

    1    1    1    0  -10

END OF READIM,
```

```
RUN NO. SICA01                          DATE 053173                              PAGE NO.    7
                                     RUN BY E.J. KUHAR

       STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
       20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

                 SUBSTRUCTURE    1   HAS   10   DOF WITH    1   BOUNDARY DOF DEFINED.

   IPDOF DEFINES DOF ORDER TO BE PRINTED
   (   1 X  10 )    ( 2) ( 3) ( 4) ( 5) ( 6) ( 7) ( 8) ( 9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20)

   1   1            1    2    3    4    5    6    7    8    9    10
```

```
     STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
     20 DOF LONGITUDINAL ROD    2 SUBSTRUCTURES

     ISUB = 2        KEPMOD = 10       MOPT = 2        IROT = 0

CARD INPUT INTEGER MATRIX IDDOF  (  1 X  1 )          ORDERS DOF'S FOR ATTACHMENT POINTS          0

  1   1   -1

END OF READIM,

CARD INPUT MATRIX K2     (  10 X  10 )          STIFFNESS MATRIX                         0

  1   1   2.00000000E 03  -2.00000000E 03   0.                0.
  2   1  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  3   2  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  4   3  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  5   4  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  6   5  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  7   6  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  8   7  -2.00000000E 03   4.00000000E 03  -2.00000000E 03   0.
  9   8  -2.00000000E 03   4.00000000E 03  -2.00000000E 03
 10   9  -2.00000000E 03   2.00000000E 03

END OF READ,

CARD INPUT MATRIX M2     (  1 X  10 )          MASS MATRIX                              0

  1   1   1.00000000E 00   1.00000000E 00   1.00000000E 00   1.00000000E 00
  1   5   1.00000000E 00   1.00000000E 00   1.00000000E 00   1.00000000E 00
  1   9   1.00000000E 00   1.00000000E 00

END OF READ,
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

SUBSTRUCTURE 2 HAS 10 DOF WITH 1 BOUNDARY DOF DEFINED.

IDDOF DEFINES DOF ORDER

(1 X 10)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	
1	1	1	2	3	4	5	6	7	8	9	10										

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

LAMBDA (EIGENVALUES)
(1 X 10)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	1.0280E-05	1.9577E 02	7.6393E 02	1.6489E 03	2.7639E 03	4.0000E 03	5.2361E 03	6.3511E 03	7.2361E 03	7.8842E 03

OMEGA (RAD/SEC)
(1 X 10)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	3.2063E-03	1.3992E 01	2.7639E 01	4.0606E 01	5.2573E 01	6.3246E 01	7.2361E 01	7.9694E 01	8.5065E 01	8.8342E 01

FREQ (HZ)
(1 X 10)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	5.1030E-04	2.2269E 00	4.3989E 00	6.4627E 00	8.3673E 00	1.0066E 01	1.1517E 01	1.2684E 01	1.3539E 01	1.4060E 01

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

PHY2

(10 X 10)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	3.1623E-01	4.4171E-01	4.2533E-01	3.9847E-01	3.6180E-01	3.1623E-01	2.6287E-01	2.0303E-01	1.3820E-01	6.9960E-02
2	1	3.1623E-01	3.9847E-01	2.6287E-01	6.9960E-02	-1.3820E-01	-3.1623E-01	-4.2533E-01	-4.4171E-01	-3.6180E-01	-2.0303E-01
3	1	3.1623E-01	3.1623E-01	-2.1053E-08	-3.1623E-01	-4.4721E-01	-3.1623E-01	-1.2960E-08	3.1623E-01	4.4721E-01	3.1623E-01
4	1	3.1623E-01	2.0303E-01	-2.6287E-01	-4.4171E-01	-1.3820E-01	3.1623E-01	4.2533E-01	6.9960E-02	-3.6180E-01	-3.9847E-01
5	1	3.1623E-01	6.9960E-02	-4.2533E-01	-2.0303E-01	3.6180E-01	3.1623E-01	-2.6287E-01	-3.9847E-01	1.3820E-01	4.4171E-01
6	1	3.1623E-01	-6.9960E-02	-4.2533E-01	2.0303E-01	3.6180E-01	-3.1623E-01	-2.6287E-01	3.9847E-01	1.3820E-01	-4.4171E-01
7	1	3.1623E-01	-2.0303E-01	-2.6287E-01	4.4171E-01	-1.3820E-01	-3.1623E-01	4.2533E-01	-6.9960E-02	-3.6180E-01	3.9847E-01
8	1	3.1623E-01	-3.1623E-01	1.2554E-08	3.1623E-01	-4.4721E-01	3.1623E-01	-8.2618E-08	-3.1623E-01	4.4721E-01	-3.1623E-01
9	1	3.1623E-01	-3.9847E-01	2.6287E-01	-6.9960E-02	-1.3820E-01	3.1623E-01	-4.2533E-01	4.4171E-01	-3.6180E-01	2.0303E-01
10	1	3.1623E-01	-4.4171E-01	4.2533E-01	-3.9847E-01	3.6180E-01	-3.1623E-01	2.6287E-01	-2.0303E-01	1.3820E-01	-6.9960E-02

```
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

CARD INPUT INTEGER MATRIX IPDOF   (   1 X   3 )        SELECTS DOF TO BE PRINTED          0

    1    1    1    0  -10

END OF READIM.
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

SUBSTRUCTURE 2 HAS 10 DOF WITH 1 BOUNDARY DOF DEFINED.

IPDOF DEFINES DOF ORDER TO BE PRINTED

```
(   1 X  10 )    ( 2) ( 3) ( 4) ( 5) ( 6) ( 7) ( 8) ( 9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20)

1    1           1    2    3    4    5    6    7    8    9    10
```

```
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

SUBSTRUCTURES READ INTO PROGRAM
(   1 X   2 )    ( 2) ( 3) ( 4) ( 5) ( 6) ( 7) ( 8) ( 9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20)

1   1            1    2
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

IENTRY = 2 NCPLS = 1 IOP = 0

```
RUN NO. SICA01                              DATE 053173                                   PAGE NO.  16
                                           RUN BY E.J. KUHAR

         STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
         20 DOF LONGITUDINAL ROD      2 SUBSTRUCTURES

         ISUB =     1          NROW1 =     1          NS1 =     1
         JSUB =     2          NROW2 =     1          NS2 =     1

 CARD INPUT MATRIX KCPL     (   2 X   2 )        COUPLING SPRING STIFFNESS MATRIX                 0

     1    1   2.00000000E 03  -2.00000000E 03
     2    1  -2.00000000E 03   2.00000000E 03

 END OF READ,
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

CONNECTIVITY FOR COUPLED SUBSTRUCTURES

(20 X 20)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1	1	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

```
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

IENTRY =    3

CARD INPUT INTEGER MATRIX KEEP   (   2 X   2 )        SELECTS KEPT/REDUCED DOF'S        0

    1    1    2    2
    2    1    8    8

END OF READIM.
```

```
STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD       2 SUBSTRUCTURES

IENTRY =    4

CARD INPUT MATRIX LAMDAO  (   1 X   1 )          P**2  REDUCTION FREQUENCY          0

   1    1   0.

END OF READ,
```

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

LAMSYS

(1 X 4)		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	1.2331E 01	1.1057E 02	3.0615E 02	6.5858E 02						

OMEGA (RAD/SEC)

(1 X 4)		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	3.5115E 00	1.0515E 01	1.7497E 01	2.5663E 01						

FREQ (HZ)

(1 X 4)		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	5.5887E-01	1.6736E 00	2.7848E 00	4.0844E 00						

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

IENTRY = 5 MD1 = 1 MD2 = 4 IOP = 0

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

PHY1

(10 X 4)			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	2.1464E-01	2.4881E-01	-1.7831E-01	2.9803E-01						
2	1	1.9576E-01	2.8771E-01	-6.2514E-02	3.9466E-01						
3	1	1.7570E-01	3.0988E-01	5.8606E-02	3.3656E-01						
4	1	1.5455E-01	3.1516E-01	1.7201E-01	1.7497E-01						
5	1	1.3242E-01	3.0359E-01	2.6207E-01	-2.6824E-02						
6	1	1.0946E-01	2.7569E-01	3.1423E-01	-2.0649E-01						
7	1	8.5826E-02	2.3264E-01	3.1889E-01	-3.1519E-01						
8	1	6.1669E-02	1.7650E-01	2.7352E-01	-3.2695E-01						
9	1	3.7146E-02	1.1021E-01	1.8425E-01	-2.4290E-01						
10	1	1.2406E-02	3.7472E-02	6.4967E-02	-8.9395E-02						

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

PHY2

(10 X	4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	2.3230E-01	1.9333E-01	-2.8139E-01	1.8050E-02						
2	1	2.4840E-01	1.3063E-01	-3.2350E-01	-1.6334E-01						
3	1	2.6293E-01	6.1967E-02	-3.0961E-01	-2.5305E-01						
4	1	2.7584E-01	-1.0276E-02	-2.4915E-01	-2.6423E-01						
5	1	2.8709E-01	-8.2839E-02	-1.5509E-01	-2.1496E-01						
6	1	2.9660E-01	-1.5187E-01	-4.2702E-02	-1.2651E-01						
7	1	3.0431E-01	-2.1333E-01	7.1972E-02	-2.1249E-02						
8	1	3.1016E-01	-2.6338E-01	1.7367E-01	7.9566E-02						
9	1	3.1409E-01	-2.9875E-01	2.4941E-01	1.5784E-01						
10	1	3.1607E-01	-3.1706E-01	2.8976E-01	2.0043E-01						

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

IENTRY = 6 NBKSB = 1

CARD INPUT INTEGER MATRIX IMODE (1 X 4) SELECTS MODES FOR BACKSUBSTITUTION 0

1 1 1 0 -4 0

END OF READIM.

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

MODES SELECTED FOR BACKSUBSTITUTION

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1	1	1	2	3	4															

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

RATIO (LAM2/LAM1)

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1 1.0000E 00	9.9954E-01	9.9470E-01	9.0210E-01						

FNORM FROM MASS NORMALIZATION

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1 1.0000E 00	9.9952E-01	9.9372E-01	7.6771E-01						

LAMBDA REVISED FROM BACKSUBSTITUTION

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1 1.2331E 01	1.1052E 02	3.0453E 02	5.9411E 02						

OMEGA (RAD/SEC)

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1 3.5115E 00	1.0513E 01	1.7451E 01	2.4374E 01						

FREQ (HZ)

(1 X 4)		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1 5.5887E-01	1.6732E 00	2.7774E 00	3.8793E 00						

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL ROD 2 SUBSTRUCTURES

PHY1
(10 X 4)

			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	2.1466E-01	2.4825E-01	-1.7859E-01	2.6118E-01						
2	1	1.9578E-01	2.8700E-01	-6.5527E-02	2.8570E-01						
3	1	1.7569E-01	3.0994E-01	5.8660E-02	2.3735E-01						
4	1	1.5452E-01	3.1579E-01	1.7473E-01	1.2689E-01						
5	1	1.3239E-01	3.0422E-01	2.6455E-01	-1.5755E-02						
6	1	1.0945E-01	2.7583E-01	3.1404E-01	-1.5011E-01						
7	1	8.5837E-02	2.3219E-01	3.1534E-01	-2.3728E-01						
8	1	6.1693E-02	1.7570E-01	2.6807E-01	-2.5189E-01						
9	1	3.7169E-02	1.0947E-01	1.7943E-01	-1.8997E-01						
10	1	1.2415E-02	3.7178E-02	6.3060E-02	-7.0438E-02						

STIFFNESS COUPLING CHECK CASE FROM ENTRY POINT 1
20 DOF LONGITUDINAL BOD 2 SUBSTRUCTURES

PHY2

		(10 X 4)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	1	2.3221E-01	1.9586E-01	-2.6302E-01	1.7473E-01						
2	1	2.4834E-01	1.3258E-01	-3.0816E-01	1.2426E-02						
3	1	2.6293E-01	6.1918E-02	-3.0704E-01	-1.7110E-01						
4	1	2.7591E-01	-1.2211E-02	-2.5970E-01	-3.1315E-01						
5	1	2.8718E-01	-8.5701E-02	-1.7323E-01	-3.6386E-01						
6	1	2.9668E-01	-1.5448E-01	-6.0666E-02	-3.0287E-01						
7	1	3.0435E-01	-2.1473E-01	6.0956E-02	-1.4644E-01						
8	1	3.1015E-01	-2.6311E-01	1.7321E-01	5.7570E-02						
9	1	3.1404E-01	-2.9693E-01	2.5909E-01	2.4509E-01						
10	1	3.1598E-01	-3.1433E-01	3.0555E-01	3.5662E-01						

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STIFFNESS COUPLING CHECK CASE FROM ENTRY ROINT 1
20 DOF LONGITUDINAL ROD     2 SUBSTRUCTURES

ENTRY POINT     6    HAS BEEN COMPLETED.
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GENERAL ELECTRIC

Space Division

Headquarters: Valley Forge, Pennsylvania ☐ Daytona Beach, Fla. ☐ Cape Kennedy, Fla. ☐ Evendale, Ohio ☐ Huntsville, Ala. ☐ Bay St. Louis, Miss. ☐ Houston, Texas ☐ Sunnyvale, Calif. ☐ Roslyn, Va. ☐ Beltsville, Md.